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A SYNOPSIS AND CRITIQUE OF FORECASTS OF SOCKEYE SALMON RETURNING TO BRISTOL BAY, ALASKA, IN 1992

by

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ABSTRACT

The total number of sockeye salmon *Oncorhynchus nerka* forecasted to return to Bristol Bay in 1992 is 39,598,000 (80% confidence interval: 17,184,000 - 62,012,000). Runs are expected to exceed spawning escapement goals for all systems. Total projected sockeye salmon harvest is expected to be 28,813,000. Most of this harvest will be taken within Bristol Bay inshore fishing districts (26,422,000), but some have been allocated to June fisheries occurring in the vicinity of the Shumagin Islands and South Unimak under an existing management plan (8.3% of total Bristol Bay projected harvest= 2,391,000). The 1992 forecast was based on the ADF&G method which averaged results from three linear regression models based on the relationship between returns and either spawner, sibling, or smolt data. Based on performance evaluations of the ADF&G method, all available data was used to forecast 1992 runs to Nushagak and Togiak Districts, but data prior to the 1978 return year were omitted from calculations for Naknek-Kvichak, Egegik and Ugashik Districts. To further correct under-forecasting errors, predictions for all Bristol Bay rivers were adjusted by the 1984-91 average percent forecast error of the corresponding systems. Although out of range data were not used in calculations, their occurrence suggested that age-1.2, age-1.3, and age-2.2 predictions for Egegik River could be too low. The outlook for 1992-1995, based only on the spawner-recruit component of the forecast and not adjusted for average historic forecast errors, is for the total sockeye salmon run to Bristol Bay to be greatest in 1994 and least in 1993, mostly due to variations in the Kvichak River run. For all years examined, runs to all river systems are expected to exceed spawning goal requirements.

KEY WORDS: Salmon forecast, sockeye salmon, *Oncorhynchus nerka*, Bristol Bay, spawner-recruit, environmental indicators

INTRODUCTION

Preseason forecasts of sockeye salmon *Oncorhynchus nerka* runs to Bristol Bay, Alaska, have been made by the Alaska Department of Fish and Game (ADF&G) since 1961 (ADF&G 1961; Appendix A.1). ADF&G biologists use forecasts to (1) estimate commercial harvests, (2) set quotas for the Shumagin Islands-South Unimak June fishery (ADF&G 1992), and (3) determine which stocks may need protection against possible overharvesting. Seafood buyers and processors use forecasts to (1) estimate the supply of raw fish which will be available for various uses, (2) determine staff and equipment needed for production of fresh, frozen, and canned products, and (3) plan deployment of tenders and processing vessels. Commercial fishermen use forecasts to decide which areas might provide them with the best fishing opportunities and to assist in decisions involving future investments for equipment and gear.

Until 1983, annual preseason forecasts made by ADF&G were usually calculated as the mean of estimates obtained from models using either spawner-recruit, sibling, or smolt data. Forecasts from this method, referred to as the ADF&G method, had a mean absolute percent error (MAPE) of 37.0 for 1961-82 (MAPE range = 2.7 - 78.0; Fried and Yuen 1987; Fried et al. 1988). Beginning in 1983, attempts were made to improve forecast accuracy by combining results from the ADF&G method with those from other methods (Eggers et al. 1983a, 1983b; Fried and Yuen 1985, 1986, 1987). However, these forecasts did not prove to be more accurate than forecasts based solely on the ADF&G method and did not correct the tendency of published forecasts to under-estimate total run size for 16 of the last 18 years (Fried et al. 1988; Appendix A.1).

Methods used to calculate run size predictions were modified again in 1988 in an attempt to remedy these problems (Fried et al. 1988; Fried and Cross 1988, 1990). The omission of data prior to the 1978 return year from all calculations was the most important change in forecast methods. We felt that models based on recent data would more accurately reflect current trends in sockeye salmon production. Most Bristol Bay river systems have shown a dramatic increase in the number of sockeye salmon adults produced by each spawner since 1978, coincident with (1) decreased interception of maturing sockeye salmon on the high seas, (2) the onset of more favorable climatic conditions, and (3) improvements in ADF&G's ability to determine and attain spawning escapement goals for most major Bristol Bay systems (Eggers et al. 1984).

Although forecasts based on only recent data decreased under-forecasting errors for river systems on the east side of Bristol Bay, there was still a tendency to under-forecast the run (six out of the last eight years). In 1991 we sought to further adjust the forecast to correct this continuing bias of under-forecasting. Several bias correction factors were evaluated in search of the most accurate forecast. Our goal was an unbiased forecast resulting in no tendency to over- or under-forecast. In 1992 we continued to analyze bias correction factors, and methods used were similar to those for the 1991 forecast.

The purpose of this report is to provide a final preseason forecast of sockeye salmon returning to Bristol Bay, Alaska, in 1992 with an outlook of abundance fluctuations through 1995. Specific objectives are to (1) to document changes in the methods used to forecast sockeye salmon runs to Bristol Bay in 1992, (2) evaluate the relative accuracy of different forecasting methods, (3) forecast annual runs for all major river systems through 1995, and (4) indicate where actual runs are most likely to depart from preseason expectations.

METHODS

Age Designation

Sockeye salmon ages were expressed according to European system designations (Koo 1962), wherein the number of annuli formed in fresh and salt water are indicated to the left and right of a decimal point. Historically, four age classes account for about 98% of total returns: 28% were age 1.2, 31% were age, 28% were age 1.3, and 11% were age 2.3. Smolt ages were expressed as either age 1. or 2., corresponding to sockeye salmon that migrated seaward in either their second or third year of life.

Forecast Data Base and Techniques

The ADF&G method forecast has been used to predict the number of sockeye salmon by major age class returning to nine river systems that account for about 98% of Bristol Bay sockeye salmon production, these are: Kvichak, Branch, Naknek, Egegik, Ugashik, Wood, Igushik, Nushagak, and Togiak Rivers (Figure 1). Forecasts for each system and age class have been calculated by averaging results of several models which used either (1) spawner-recruit, (2) sibling, or (3) smolt data. Prior to 1986, predictions for each data component were calculated by averaging results from two or more models (e.g. linear regression, ratio estimator, mean proportion; Eggers et al. 1983a, 1983b). Beginning in 1986, only results from a single model per component (spawner-recruit, sibling, or smolt) were calculated and averaged for the forecast (Fried and Yuen 1986, 1987).

Forecasts for 1992 were first calculated using all available data (referred to as the All Data ADF&G method) and then recalculated with all data prior to the 1978 return year excluded from calculations (referred to as the Recent Data ADF&G method).

Predicted returns from spawner-recruit data were based on a linear form of the Ricker (1954) curve constructed for age-specific returns (Brannian et al. 1982):

$$\ln\left(\frac{R_{a,r,y}}{E_{r,y}}\right) = \ln(\alpha) + \beta E_{r,y} + \epsilon \quad (1)$$

where:

$R_{a,r,y}$ = number of age-*a* sockeye salmon returning to river system *r* from brood year *y*,

$E_{r,y}$ = total number of spawners in river system *r* during brood year *y*,

α,ß = regression coefficients estimated by least square methods, and

ϵ = random error with mean, 0, and variance s^2.

In cases where the Ricker relationship was not significant at the 25% level (F-test, Ho: ß = 0, P > 0.25; Snedecor and Cochran 1969), a linear regression model based on natural logarithm transformed data was used:

$$\ln(R_{a,r,y}) = \alpha + \beta \ln(E_{r,y}) + \epsilon \quad (2)$$

Predicted returns from sibling (younger age classes from the same brood year) and smolt data were also based upon linear regression models using natural logarithm transformed data, as suggested by Peterman (1982a, 1982b):

$$\ln(R_{a,r,y}) = \alpha + \beta \ln(S_{j,r,y}) + \epsilon \quad (3)$$

where:

$S_{j,r,y}$ = either the number of age-*j* smolt (where j = age 1. or 2.) migrating from river system *r* which were progeny of brood year *y*, or the number of age-*j* adults (where j =[a-1]) returning to river system *r* from spawning in brood year *y*.

Smolt data were available for four of the nine river systems for which forecasts were made. Smolt enumeration programs using sonar equipment were begun in 1971 for Kvichak (Russell 1972), 1975 for Wood (Krasnowski 1976), 1982 for Egegik (Bue 1984), and 1983 for Ugashik (Fried et al. 1987) River systems.

Results from models were excluded from final forecast calculations if the model was not significant at the 25% level ($P > 0.25$) or the value of the input variable ($E_{r,y}$ or $S_{j,r,y}$) was outside the range of data used to build the model. If results from spawner-recruit, sibling or smolt models did not meet these criteria for a river system age class, the mean return of that age class to that river system was used as the prediction. For All Data ADF&G method forecasts, mean returns for all past years (1956-91) were used. For Recent Data ADF&G method forecasts, mean returns for the past 14 years 1978-91, were used.

Evaluation of Forecast Performance

Comparison of Recent and All Data Forecasts

Since the Recent Data ADF&G method was first used for the 1988 forecast, a hindcasting procedure, in which only data prior to the year of interest were used to build models, was used to simulate its past performance for several past years. Due to the limited amount of data available (all data prior to the 1978 return year were omitted from analyses), Recent Data ADF&G method hindcasts could be calculated for only eight years, 1984-91. Hindcasts prior to 1984 could not be calculated because most models were not significant at the 25% level ($P > 0.25$) and many of the input data were out of range of values used for models.

Recent Data ADF&G method hindcasts for 1984-91 were compared with All Data ADF&G method hindcasts for the same period to determine which method could be expected to produce less biased and more accurate forecasts. Three statistics were used for comparisons: percent error (PE), mean percent error (MPE), and mean absolute percent error (MAPE). PE is a measure of annual performance:

$$PE = 100\left(\frac{F_{i,r} - A_{i,r}}{A_{i,r}}\right) \tag{4}$$

where:

$F_{i,r}$ = forecasted total return of sockeye salmon for year i and river system r, and

$A_{i,r}$ = actual total return of sockeye salmon for year i and river system r.

MPE is a measure of bias:

$$MPE = \frac{\sum_{i=1}^{N} 100\left(\frac{F_{i,r} - A_{i,r}}{A_{i,r}}\right)}{N} \tag{5}$$

where:

N = number of years.

MAPE is measure of overall accuracy which treats under- and over-forecasting errors similarly:

$$MAPE = \frac{\sum_{i=1}^{N} 100\left(\frac{|F_{i,r} - A_{i,r}|}{A_{i,r}}\right)}{N} \tag{6}$$

Modeling Historic Forecast Errors

In an effort to reduce the tendency to under-forecast runs to Bristol Bay, we looked at ways to model historic forecast errors and develop a bias adjustment factor for the 1992 forecast. We investigated the trends in forecast errors for predictions based on All Data and Recent Data. We compared baywide forecast errors, east versus westside forecast errors, and individual river system forecast errors.

Predictions based on All Data were hindcasted for years 1965-91 using the same methods described above for the 1992 forecast. Errors in numbers of fish for the 1965-91 All Data forecasts were modeled using a linear regression model:

$$Y_i = \alpha + \beta i + \epsilon \tag{7}$$

and a second-order polynomial regression model:

$$Y_i = \alpha + \beta_1 i + \beta_2 i^2 + \epsilon \tag{8}$$

where:

Y_i = predicted run - actual run for year i,

α,β = regression coefficients estimated by least square methods, and

ϵ = random error with mean, 0, and variance s^2.

Errors for All Data forecasts were also modeled using Box-Jenkins forecasting procedures (Chatfield 1984). Autoregressive integrated moving average (ARIMA) models were fitted to forecast errors in numbers of fish or percent error (PE). The most appropriate model for the data was an AR(1) model and forecast errors were predicted as:

$$PE_i = \alpha + \beta PE_{i-1} \tag{9}$$

where model coefficients (α,β) were estimated using STATGRAPHICS[2] (Statistical Graphics Systems, 1988) computer software.

Predictions based on Recent Data were hindcasted only for years 1984-91 because of the limited data base. With only eight years of Recent Data forecast errors available, regression and time series modeling techniques could not be used. Therefore, an adjustment factor for the 1992 forecast was estimated by taking the mean percent error from 1984-91 Recent Data forecasts.

Although forecast errors by river system were analyzed individually, we decided to base the 1992 adjustment factor on models which described forecasts errors for eastside systems

[2] Use of a company name or product name does not constitute endorsement.

combined and westside systems combined. Consequently, adjustment factors for the total eastside forecast and total westside forecast were estimated. The 1992 final adjustment factor was apportioned to individual river forecasts based on each river's contributions to the total combined forecast.

Confidence Intervals

The 80% confidence interval (80% CI) for the total run forecast was calculated as:

$$80\%\ CI = F \pm t_{0.2} s_{\hat{t}} \tag{10}$$

where:

F = forecasted total run of sockeye salmon to all of Bristol Bay (total of river system predictions) in 1992,

$s_{\hat{t}}$ = standard error of the forecasted total run of sockeye salmon to Bristol Bay in 1992, and

$t_{0.2}$ = Student's t value with a probability of type I error of 0.20.

Estimation of ($s_{\hat{t}}$) was based on the mean squared error (MSE) calculated from total run predictions using the same techniques as 1992 made for 1984-91:

$$s_{\hat{t}} = \sqrt{MSE}\ , \tag{11}$$

$$MSE = \frac{\sum_{i=1}^{N} (F_i - A_i)^2}{N - 2} \tag{12}$$

where:

F_i = forecasted total return of sockeye salmon for year *i*,
A_i = actual total return of sockeye salmon for year *i*, and
N = number of years (1984-91).

Outlook to 1995

Forecasts were made for the years 1993, 1994, and 1995 using only spawner-recruit data (equation 1 or 2). These forecasts were not adjusted for historic forecast errors. Sockeye salmon production and mean June Cold Bay air temperatures were also examined to determine whether the positive correlation between these factors noted in previous studies (Eggers et al. 1984) was still evident.

A total Bristol Bay return per spawner (RPS) value for each return year (*y*) was calculated from the weighted sum of total escapements four ($E_{(y-4)}$), five ($E_{(y-5)}$), and six ($E_{(y-6)}$) years prior to each total return:

$$RPS_y = \frac{R_y}{P_{1.2}E_{y-4} + (P_{1.3} + P_{2.2})E_{y-5} + P_{2.3}E_{y-6}} \tag{13}$$

where:

$P_{1.2}$, $P_{1.3}$, $P_{2.2}$, and $P_{2.3}$ = mean proportions of age-1.2, age-1.3, age-2.2, and age-2.3 sockeye salmon returning to Bristol Bay each year.

The air temperature index (ATI) for each return year *y* was calculated from the weighted sum of mean June air temperatures recorded at Cold Bay, Alaska, one ($T_{(y-1)}$), two ($T_{(y-2)}$), and three ($T_{(y-3)}$) years prior to each total return:

$$ATI_y = \frac{(P_{1.3} + P_{2.3})T_{y-3} + T_{y-2} + T_{y-1}}{(P_{1.3} + P_{2.3}) + 2} \tag{14}$$

Deviations (D) from the mean were then calculated for actual (1965-91) and forecasted

(1992-95) RPS value:

$$D_{RPS,y} = \left(RPS_y - \overline{RPS}\right) \tag{15}$$

and for ATI values associated with each actual (1965-91) RPS value:

$$D_{ATI,y} = \left(ATI_y - \overline{ATI}\right) \tag{16}$$

Finally, a plot was made of all deviations that could be calculated for the period 1965-91, and the correlation coefficient (Snedecor and Cochran 1969) between $D_{RPS,y}$ and $D_{ATI,y}$ was calculated for 1965-91.

RESULTS

Performance of Recent and All Data Forecasts

Justification for use of the Recent Data ADF&G method was based on the observation that the number of returning adults produced per spawner has shown a dramatic increase since 1978 (Fried et al. 1988). It was hoped that use of only recent data would provide a more accurate estimate of total sockeye salmon returns and would help correct the past bias of under-forecasting annual runs. If results for 1984-91 are representative of future performance, then forecasts of total sockeye salmon returns to Bristol Bay based on the Recent Data ADF&G method should be less biased (MPE=-11.8) and more accurate (MAPE=22.6) than forecasts based on the All Data ADF&G method (MPE=-40.9; MAPE=40.9; Appendix B.1).

Unfortunately, results for individual river systems strongly suggested that the All Data ADF&G method was more accurate and less biased for Wood, Igushik, Nuyakuk, and Togiak than the Recent Data method (Appendix B.1). Results for Nushagak and Togiak District systems based on the Recent Data ADF&G method showed a three- to five-fold decrease in accuracy as well as a large bias towards over-forecasting when compared to results based on the All Data ADF&G method. Results for Kvichak River suggested that the Recent Data method was less biased than the All Data method (Recent MPE = 12.9, All MPE = -19.2) but less accurate (Recent MAPE = 67.3, All MAPE = 51.1).

We tried to balance gains and losses in total Bristol Bay and individual river system forecast bias and accuracy by using results of the Recent Data ADF&G method for some systems and the All Data ADF&G method for the remaining systems. For the 1992 forecast, we used Recent Data for eastside river systems (Kvichak, Branch, Naknek, Egegik, and Ugashik) and All Data for westside river systems (Wood, Igushik, Nushagak, and Togiak). This method is similar to that used for the 1989-91 forecasts and is referred to as the Mixed Data ADF&G method (Appendix B.2). We felt it would provide the least biased and most accurate (MPE = -21.5, MAPE = 25.3) forecast of total returns to Bristol Bay and would also furnish reasonable individual river system forecasts.

Unadjusted River System Forecasts

Results from models were excluded from final river system forecast calculations if the model was not significant at the 25% level ($P > 0.25$) or the value of the input variable ($E_{r,y}$ or $S_{j,r,y}$) was outside the range of data used to build the model. If results from spawner-recruit, sibling and smolt models did not meet these criteria for a river system age class, the mean return for 1978-91 was used for eastside rivers (Recent Data) and the mean return for 1956-91 (All Data) was used for westside rivers.

Kvichak River

Spawner-recruit, sibling, and smolt data bases were available for estimating Kvichak River run sizes in 1992.

Age 1.2. The age-1.2 forecast for this system was based upon spawner-recruit and smolt data (Appendix C.1). A prediction based on sibling data could not be made because the regression model was not significant at the 25% level ($P > 0.25$). The spawner-recruit estimate of 2,578,000 was similar to the smolt estimate of 2,539,000. The average of the two estimates was 2,558,000.

Age 2.2. The age-2.2 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix C.1). The spawner-recruit estimate of 5,823,000 was similar to the sibling estimate of 5,634,000, but was 65.0% greater than the smolt estimate of 3,530,000. The average of the three estimates was 4,996,000.

Age 1.3. The age-1.3 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix C.1). The spawner-recruit estimate of 2,086,000 was 44.6% greater than the sibling estimate of 1,443,000 and 24.0% greater than the smolt estimate of 1,682,000. The average of the three estimates was 1,737,000.

Age 2.3. The age-2.3 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix C.1). The spawner-recruit estimate of 301,000 was about 23.2% less than the sibling estimate of 392,000, but 20.4% greater than the smolt estimate of 250,000. The average of the three estimates was 314,000.

Branch River

Spawner-recruit and sibling data bases were available for estimating Branch River run sizes in 1992. There has never been a smolt project on the Branch River.

Age 1.2. The age-1.2 forecast was based upon spawner-recruit and sibling data (Appendix C.2). The spawner-recruit estimate of 212,000 was 34.2% greater than the sibling estimate of 158,000. The average of the two estimates was 185,000.

Age 2.2. The age-2.2 forecast was based only upon spawner-recruit data (Appendix C.2). A prediction based on sibling data could not be made because no age-2.1 siblings were present in Branch River samples in 1991. The spawner-recruit estimate was 34,000.

Age 1.3. The age-1.3 forecast was based only upon spawner-recruit data (Appendix C.2). The prediction based on sibling data was not used because the model was not significant at the 25% level ($P > 0.25$). The spawner-recruit estimate was 188,000.

Age 2.3. The age-2.3 forecast was based on the mean return of this age class for 1978-91. The prediction based on spawner-recruit data was not used because the model was not significant at the 25% level ($P > 0.25$; Appendix C.2). A prediction based on sibling data was not used because the age-2.2 sibling return in 1991 was greater than past values used to build the model. The mean return estimate was 21,000.

Naknek River

Spawner-recruit and sibling data bases were available for estimating Naknek River run sizes in 1992. The smolt project on the Naknek River has not operated since 1986.

Age 1.2. The age-1.2 forecast was based only upon spawner-recruit data (Appendix C.3). A prediction based on sibling data could not be made because no age-1.1 sockeye salmon were present in Naknek River samples from 1991. The spawner-recruit estimate was 446,000.

Age 2.2. The age-2.2 forecast was also based only upon spawner-recruit data (Appendix

C.3). A predictions based on sibling data was not used because the model was not significant at the 25% level ($P > 0.25$). The spawner-recruit estimate was 642,000.

Age 1.3. The age-1.3 forecast was based on spawner-recruit and sibling data (Appendix C.3). The spawner-recruit estimate of 1,259,000 was 15.2% greater than the sibling estimate of 1,093,000. The average of the two estimates was 1,176,000.

Age 2.3. The age-2.3 forecast was based on spawner-recruit and sibling data (Appendix C.3). The spawner-recruit estimate of 1,058,000 was only 2.4% less than the sibling estimate of 1,084,000. The average of the two estimates was 1,071,000.

Egegik River

Spawner-recruit, sibling, and smolt data bases were available for estimating Egegik River run sizes in 1992.

Age 1.2. The age-1.2 forecast was based on sibling and smolt data (Appendix C.4). A prediction based on spawner-recruit data was not used because spawning escapement in 1988 was greater than past values used to build the model. The sibling estimate of 839,000 was 43.2% greater than the smolt estimate of 586,000. The average of the two estimates was 712,000.

Age 2.2. The age-2.2 forecast was based upon spawner-recruit and sibling data (Appendix C.4). A prediction based on smolt data was not used because age-2. smolt production in 1990 was greater than past values used to build the model. The spawner-recruit estimate of 4,163,000 was 12.0% less than the sibling estimate of 4,731,000. The average of the two estimates was 4,447,000.

Age 1.3. The age-1.3 forecast was based only upon sibling data (Appendix C.4). A prediction based on spawner-recruit data was not used because spawning escapement in 1987 was greater than past values used to build the model. A prediction based on smolt data was not used because age-1. smolt production in 1989 was greater than past values used to build the model. The sibling estimate was 1,541,000.

Age 2.3. The age-2.3 forecast for this system was based upon spawner-recruit, sibling, and smolt data (Appendix C.4). The spawner-recruit estimate of 1,380,000 was 13.9% less than the sibling estimate of 1,602,000, and 37.9% less than the smolt estimate of 2,221,000. The average of the three estimates was 1,734,000.

Ugashik River

Spawner-recruit, sibling, and smolt data bases were available for estimating Ugashik River run sizes in 1992.

Age 1.2. The age-1.2 forecast was based upon spawner-recruit and sibling data (Appendix C.5). The prediction based on smolt data was not made since the model was not significant at the 25% level (P > 0.25). The spawner-recruit estimate of 623,000 was 36.1% less than the sibling estimate of 975,000. The average of the two estimates was 799,000.

Age 2.2. The age-2.2 forecast was based upon spawner-recruit and sibling data (Appendix C.5). The prediction based on smolt data was not used because the model was not significant at the 25% level (P > 0.25). The spawner-recruit estimate of 1,065,000 was 26.8% less than the sibling estimate of 1,455,000. The average of the two estimates was 1,260,000.

Age 1.3. The age-1.3 forecast was based upon spawner-recruit and sibling data (Appendix C.5). The prediction based on smolt data was not used because the model was not significant at the 25% level (P > 0.25). The spawner-recruit estimate of 672,000 was 28.5% less than the sibling estimate of 940,000. The average of the two estimates was 806,000.

Age 2.3. The age-2.3 forecast was based upon spawner-recruit and sibling data (Appendix C.5). The prediction based on smolt data was not used because the model was not significant at the 25% level (P > 0.25). The spawner-recruit estimate of 523,000 was 10.0% less than the sibling estimate of 581,000. The average of the two estimates was 552,000.

Wood River

Spawner-recruit, sibling, and smolt data bases were available for estimating Wood River run sizes in 1992.

Age 1.2. The age-1.2 forecast was based upon spawner-recruit, sibling, and smolt data (Appendix C.6). The spawner-recruit estimate of 733,000 was only 4.1% less than the sibling estimate of 764,000 and 2.5% greater than the smolt estimate of 715,000. The average of the three estimates was 737,000.

Age 2.2. The age-2.2 forecast was based upon spawner-recruit and sibling data (Appendix C.6). A prediction based on smolt data was not used because the age-2. smolt production in 1990 was less than past values used to build the model. The spawner-recruit estimate of 111,000 was 19.4% greater than the sibling estimate of 93,000. The average of the two estimates was 102,000.

Age 1.3. The age-1.3 forecast was based upon spawner-recruit, sibling, and smolt data

(Appendix C.6). The spawner-recruit estimate of 1,037,000 was 11.0% greater than the sibling estimate of 934,000 but about 24.9% less than the smolt estimate of 1,381,000. The average of the three estimates was 1,117,000.

Age 2.3. The age-2.3 forecast was based on spawner-recruit, sibling, and smolt data (Appendix C.6). The spawner-recruit estimate of 52,000 was about 13.0% greater than the sibling estimate of 46,000 and similar to the smolt estimate of 51,000. The average of the three estimates was 50,000.

Igushik River

Spawner-recruit and sibling data bases were available for estimating Igushik River run sizes in 1992. There has never been a smolt project on the Igushik River.

Age 1.2. The age-1.2 forecast was based only upon results from spawner-recruit data (Appendix C.7). A prediction based on sibling data was not made because no age-1.1 sockeye salmon were present in samples collected from the Igushik River in 1991. The spawner-recruit estimate was 86,000.

Age 2.2. The age-2.2 forecast was based only on spawner-recruit data (Appendix C.7). A prediction based on sibling data was not made because no age-2.1 sockeye salmon were present in samples collected from the Igushik River in 1991. The spawner-recruit estimate was 28,000.

Age 1.3. The age-1.3 forecast was based upon spawner-recruit and sibling data (Appendix C.7). The spawner-recruit estimate of 365,000 was 6.9% less than the sibling estimate of 392,000. The average of the two estimates was 379,000.

Age 2.3. The age-2.3 forecast was based upon spawner-recruit and sibling data (Appendix C.7). The spawner-recruit estimate of 42,000 was 31.2% greater than the sibling estimate of 32,000. The average of the two estimates was 37,000.

Nushagak River

Predictions were not made for the Nushagak River drainage prior to 1992. In past years only returns to Nuyakuk River (a major tributary to Nushagak River) were predicted. There has not been a counting tower on the Nuyakuk River since 1988 and the smolt enumeration project ended in 1989. Therefore, a database to predict Nuyakuk River returns is no longer available.

A sonar project to count adult salmon entering the Nushagak River mainstem has operated since 1979. At the time of this report, reliable age information for sockeye salmon returning to Nushagak River was available from only 1985-91. Consequently, total return by age estimates for Nushagak River from 1985-91 were used to make predictions for 1992. Because the data base was relatively short, mean return by age was used as the predictor.

Age 1.2. The 1985-91 mean return to Nushagak River of age-1.2 sockeye salmon was 91,000. Age-1.2 returns varied from 38,000 to 170,000.

Age 2.2. The 1985-91 mean return to Nushagak River of age-2.2 sockeye salmon was 3,000. Age-2.2 returns varied from 0 to 6,000.

Age 1.3. The 1985-91 mean return to Nushagak River of age-1.3 sockeye salmon was 664,000. Age-1.3 returns varied from 344,000 to 1,476,000.

Age 2.3. The 1985-91 mean return to Nushagak River of age-2.3 sockeye salmon was 8,000. Age-2.3 returns varied from 3,000 to 32,000.

Age 0.X. The 1985-91 mean return to Nushagak River of age-0.X sockeye salmon was 722,000. Age-0.X returns varied from 239,000 to 1,060,000.

Togiak River

Spawner-recruit and sibling data bases were available for estimating Togiak River run sizes in 1992. Smolt projects were not operated on the Togiak River in 1989 or 1990. A smolt project was operated on Togiak River on in 1988.

Age 1.2. The age-1.2 forecast was based only on spawner-recruit data (Appendix C.8). A prediction based on sibling data was not made because the regression model was not significant at the 25% level ($P > 0.25$) and no age 1.1 sockeye salmon were present in Togiak River samples in 1991. The spawner-recruit estimate was 88,000.

Age 2.2. The age-2.2 forecast was based only on spawner-recruit data (Appendix C.8). The prediction based on sibling data was not used because the regression model was not significant at the 25% level ($P > 0.25$) and no age-2.1 sockeye salmon were present in Togiak River samples in 1991. The spawner-recruit estimate was 26,000.

Age 1.3. The age-1.3 forecast was based on spawner-recruit and sibling data (Appendix C.8). The spawner-recruit estimate of 335,000 was 9.8% greater than the sibling estimate of 305,000. The average of the two estimates was 320,000.

Age 2.3. The age-2.3 forecast for this system was based on spawner-recruit and sibling data (Appendix C.8). The spawner-recruit estimate of 26,000 was 31.6% less than the sibling estimate of 38,000. The average of the two estimates was 32,000.

Historic Forecast Errors and 1992 Forecast Adjustment

All Data Forecast Errors

Forecast errors for the eastside river systems based on All Data showed an increasing trend from 1966-91 (Figure 2). Linear and polynomial regression models of the relationship between forecast year and eastside forecast error were significant ($P < 0.01$; Figures 3, 4). The 1992 prediction for combined eastside systems based on All Data was 19.2 million sockeye salmon. The estimated error for the 1992 prediction based on the linear and polynomial regression models were -19.2 million and -21.5 million (Table 1). A Box-Jenkins time series AR(1) model was estimated for the relationship between forecast year and eastside relative forecast errors (percent error; Figure 5). The time series model estimated -101.1%, or -19.4 million fish error for the 1992 eastside All Data prediction (Table 1). Therefore, estimated error adjustments for an eastside All Data prediction were greater than or similar to the original prediction (Table 1).

The performance of using All Data to predict eastside systems and correcting the prediction by an adjustment factor based on a linear regression or time series models was reviewed by hindcasting runs with these techniques. Correcting All Data predictions by errors estimated from linear regression models resulted in over-forecasts for 1984-88 and under-forecasts for 1989-91 (Figure 6). The MPE of All Data predictions corrected by linear regression models was +12.7% for 1984-91 compared to -44.3% for unadjusted predictions. Correcting All Data predictions by errors estimated from time series models resulted in over-forecasts for 1986 and 1988 and under-forecasts for 1987 and 1989-91 (Figure 7). The MPE of All Data predictions corrected by time series models was -7.1% for 1986-91 compared to -47.3% for unadjusted predictions.

Errors of westside forecasts (Wood, Igushik, and Togiak) based on All Data showed no trend through time (Figure 8). Linear and polynomial regression models of the relationship between year and westside forecast error were not significant ($P > 0.25$; Figures 9, 10). The 1992 prediction for combined westside systems (Wood, Igushik, and Togiak) based on All Data was 4.5 million sockeye salmon. The estimated error for the 1992 prediction based on the linear and polynomial regression models were -3.0 million and -0.9 million (Table 1). Because the regression models of combined westside (All Data) forecast errors were not statistically significant, we also looked at the 1984-91 average error of All Data forecasts. We only looked at 1984-91 because we wanted to see how All Data forecasts for Wood, Igushik, and Togiak Rivers performed in more recent years. The 1984-91 average error of All Data forecasts for Wood, Igushik, and Togiak Rivers was -1.1 million (-36.4%).

The performance of using All Data to predict westside systems and correcting the prediction by an adjustment factor based on a linear regression model or the 1984-91 average error was reviewed by hindcasting runs with these techniques. Correcting All Data westside predictions by errors estimated from linear regression models resulted in over-forecasts for

1984-90 and an under-forecast for 1991 (Figure 11). The MPE of All Data westside predictions corrected by linear regression models was +63.0% for 1984-91 compared to -26.0% for unadjusted predictions. Correcting All Data westside predictions by the 1984-91 average error resulted in under-forecast for 1987-91 (Figure 12). The MPE of All Data westside predictions corrected by the 1984-91 average error was -21.6% for 1987-91 compared to -32.3% for unadjusted predictions.

Recent Data Forecast Errors

Errors of eastside forecasts based on Recent Data were generally negative (forecasted run less than actual run), but showed no trend through time for the years 1984-91 (Figure 13). Because errors of Recent Data eastside forecasts were not correlated with time, the 1984-91 average error (-34.9%) was used as an estimate of the 1992 prediction error. The 1992 prediction for combined eastside systems based on Recent Data was 25.2 million fish. The estimated error for the 1992 eastside prediction based on average errors was -8.8 million fish (Table 1). Using the average error to adjust Recent Data forecasts for eastside systems resulted in under-forecasts in 1987, 1989-91 and an over-forecast for 1988 (Figure 14). The 1987-91 MPE for Recent Data eastside forecasts was reduced from -25.8% to -10.3% by adjusting for previous years average error.

Errors of westside (Wood, Igushik, Togiak) forecasts based on Recent Data were generally positive (forecasted run more than actual run), and errors seemed to get smaller through time for the years 1984-91 (Figure 15). The 1984-91 average error (+20.2%) was used as an estimate of the 1992 prediction error. The 1992 prediction for combined westside systems based on Recent Data was 5.9 million fish. The estimated error for the 1992 westside prediction based on average errors was +1.2 million fish (Table 1). Using the average error to adjust Recent Data forecasts for westside systems resulted in under-forecasts in 1987-91 (Figure 16). The 1987-91 MPE for Recent Data westside forecasts was increased from +0.8% to -37.8% by adjusting for previous years average error. Because errors of the Recent Data westside forecasts decreased through time, correcting by a simple average decreased rather than improved the accuracy of the more recent years predictions.

1992 Forecast Adjustment

Errors in All Data eastside forecasts showed an increasing trend from 1966-91. However, they were clustered in two groups. Prior to 1978 forecasts were greater than or equal to actual runs and after 1978 forecasts were less than actual runs (Figure 2). Because eastside errors appeared to be clustered in time, we felt that regression analysis was not appropriate. Regression and time series models estimated adjustment factors for the 1992 eastside All Data forecast which were similar or larger than the original forecast. We decided that using Recent Data to forecast the eastside systems and adjusting by a smaller number of fish was preferable to using the entire data base (All Data) and adjusting by a very large number.

Therefore, we decided to use the Recent Data forecast for the eastside systems and increased it by the 1984-91 average error (34.9% or 8.8 million fish), thus the total forecast for the eastside systems combined equaled 34.0 million.

Based on hindcasting results using All Data to forecast westside systems is less biased and more accurate (MPE=-20.3, MAPE=22.2) than using Recent Data (MPE=52.9, MAPE=61.7). Recent Data forecasts for westside systems were greater than the run in six of eight years. Correcting Recent Data westside forecasts by the 1984-91 average error resulted in under-forecasts in all five years tested. Because All Data appeared to forecast west side systems more accurately, we decided to use All Data instead of Recent Data. Linear and polynomial regression models of All Data westside forecast errors were not significant, therefore we did not use regression analysis. Instead, we increased the 1992 All Data westside forecast by the 1984-91 average error of 36.4% or 1.1 million fish.

Adjusted Total Bristol Bay Forecast

Based on results of the Mixed Data method adjusted by the 1984-91 average percent error, a total of 39,598,000 sockeye salmon (80% CI: 17,184,000 - 62,012,000) are expected to return to Bristol Bay in 1992 (Table 2). This level of production would be about 37.1% (10,715,000 sockeye salmon) greater than the 20-year (1972-1991) mean return of 28,853,000 (range: 3,517,000 to 66,293,000), and about 7.9% (2,911,000) greater than the most recent 10-year (1982-1991) mean return of 36,687,000 (range: 23,996,000 - 48,971,000).

Total projected sockeye salmon harvest is 28,813,000 (80% CI: 6,399,000 - 51,227,000; Table 2). Most (26,422,000) of this harvest will be taken within Bristol Bay inshore fishing districts (Table 3). The remainder of the sockeye harvest (8.3% of total Bristol Bay harvest = 2,391,000) has been allocated to fisheries occurring in June in the vicinity of Shumagin Islands and South Unimak under an existing management plan (regulation 5AAC 09.365, ADF&G 1992). No estimate is available of the number of Bristol Bay sockeye salmon expected to be harvested by foreign or domestic high seas fisheries.

The total number of sockeye salmon expected to return to Bristol Bay, after the Shumagin Islands and South Unimak fisheries have occurred is 37,207,000 (Table 3). Runs should exceed spawning escapement goals for all river systems. The projected Bristol Bay combined fishing district harvest of 26,422,000 would be 57.3% (9,622,000) greater than the 20-year (1972-1991) mean harvest of 16,800,000 (range: 761,000 - 37,372,000), and 12.4% greater (2,922,000) greater than the 10-year (1982-1991) mean harvest of 23,500,000 (range: 14,006,000 - 37,372,000).

Adjusted River System Forecasts

The combined prediction for eastside river systems (Kvichak, Branch, Naknek, Egegik, and Ugashik) was increased by the 1984-91 average forecast error of 34.9%. The combined prediction for westside river systems (Wood, Igushik, and Togiak) was increased by the 1984-91 average forecast error of 36.4%. Forecasts for individual rivers were increased proportionally based on their contribution to the combined east or westside prediction.

Kvichak River

A total of 12,956,000 sockeye salmon were forecasted to return to this system (Table 3). Sockeye salmon production within the Kvichak River system has followed a five-year abundance cycle (Mathisen and Poe 1981). A return of 12,956,000 sockeye salmon to the Kvichak River system in 1992, a non-peak year, would be about 127.3% greater than the mean return of 5,700,000 sockeye salmon (range: 337,000 - 20,983,000) observed during past "non-peak" years (1962-63, 1967-68, 1972-73, 1977-78, 1982-83, 1987-88). Age-2.2 sockeye salmon comprised 52.0% of the forecasted Kvichak River return in 1992.

Branch River

A total of 578,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be about 13.1% greater than the mean return of 511,000 for 1982-1991 (range: 283,000 - 861,000), and about 43.4% greater than the mean return of 403,000 for 1972-1991 (range: 55,000 - 861,000). Age-1.2 and age-1.3 comprised 43.2% and 43.9% of the Branch River forecast.

Naknek River

A total of 4,498,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be 5.5% less than the mean return of 4,760,000 for 1982-91 (range: 1,796,000 - 10,353,000) and 14.9% more than the mean return of 3,914,000 for 1972-91 (range: 724,000 - 10,353,000).

Egegik River

A total of 11,376,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be about 37.7% greater than the mean return of 8,264,000 for 1982-91 (range: 3,918,000 - 12,611,000), but about 108.9% greater than the mean return of 5,446,000 for 1972-91 (range: 790,000 - 12,611,000). Age-1.2, age-2.2, and age-1.3 returns could be greater than forecasted based on spawner and smolt data which had greater values than past years included in the models (Appendix C.4). The forecast for Egegik River was 53% age-2.2 sockeye salmon.

Ugashik River

A total of 4,608,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be about 4.0% greater than the mean return of 4,430,000 for 1982-91 (range: 2,256,000 - 7,875,000) but about 63.5% greater than the mean return of 2,818,000 for 1972-91 (range: 60,000 - 7,875,000). All four major age classes were well represented in the 1992 Ugashik River forecast.

Wood River

A total of 2,737,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be similar to the mean return of 2,756,000 for 1982-91 (range: 1,694,000 - 4,925,000) and about 2.2% greater than the mean return of 2,677,000 for 1972-91 (range: 716,000 - 4,925,000). The 1992 Wood River forecast was comprised of 36.8% age-1.2 and 55.7% age-1.3 sockeye salmon.

Igushik River

A total of 721,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be about 34.0% less than the mean return of 1,093,000 for 1982-91 (range: 415,000 - 2,573,000) and about 32.5% less than the mean return of 1,068,000 for 1972-91 (range: 133,000 - 3,276,000). Approximately 71.6% of the 1992 Igushik River forecast was comprised of age-1.3 sockeye salmon.

Nushagak River

A total of 1,488,000 sockeye salmon were forecasted to return to this system (Table 3). This is the first year a forecast for the entire Nushagak River drainage (Nushagak, Mulchatna, and Nuyakuk Rivers) was made based on mean numbers of total returns from 1985-91. The 1992 Nushagak River forecast was comprised of 44.6% age-1.3 and 48.5% zero freshwater aged sockeye salmon.

Togiak River

A total of 636,000 sockeye salmon were forecasted to return to this system (Table 3). A total run of this size would be about 9.3% greater than the mean return of 582,000 for 1982-91 (range: 179,000 - 1,002,000), and about 11.4% greater than the mean return of 571,000 for 1972-91 (range: 177,000 - 1,173,000). About 68.7% of the sockeye salmon forecasted to return to the Togiak River in 1992 were age 1.3.

Expected Forecast Performance

Our best estimate of sockeye salmon run size for 1992 was based on the Mixed Data method. Subsequently forecasts for eastside systems (Kvichak, Branch, Naknek, Egegik, and Ugashik) and westside systems (Wood, Igushik, and Togiak) were adjusted upwards to correct for the 1984-91 average percent error. Although this forecast is our best estimate of returning run size, differences among the various forecasting components and methods suggested that deviations would be most likely to occur in four areas:

River System	Most Probable Deviation from Forecasted Return	Reason for Probable Deviation
Kvichak	less than expected return of age-2.2 sockeye salmon	The smolt forecast indicated less age-2.2 returns than either spawner or sibling forecast.
Egegik	greater than expected return of age-1.2 sockeye salmon	The number of spawners in 1988 was greater than any of those previously recorded.
	greater than expected return of age-2.2 sockeye salmon	The number of age-2. smolt that migrated in 1990 was greater than any of those previously recorded.
	greater than expected return of age-1.3 sockeye salmon	The number of age-1. smolt that migrated in 1989 was greater than any of those previously recorded.
Nushagak-Mulchatna	greater or less returns of sockeye salmon	This is the first year a forecast has been made for Nushagak-Mulchatna. The data base is relatively short.

Togiak	less than expected returns of age-1.2 and age-1.3 sockeye salmon	Parent year escapements were comprised of low percentages of age-1.2 and age-1.3 sockeye salmon.

This is the second year ADF&G adjusted the forecast based on historic forecast errors. If the 1992 run is similar to runs occurring in the past ten years, the forecast should be close to the actual run. However, if the 1992 run is more similar to the runs which occurred during the last three years, the forecast will be conservative again. Conversely, if the 1992 run is below average as were the 1986 and 1988 runs, the 1992 forecast will be too high. Other indicators that can be used to assess preseason forecast accuracy will not be available until June 1992 when the Shumagin Islands-South Unimak commercial fishery and the Port Moller offshore test fishery (operated by the University of Washington with funding from the fishing industry) take place. Catch, effort, and age composition data collected from these fisheries have been used with varying degrees of success in past years to modify preseason expectations (Eggers and Shaul 1987; Fried and Hilborn 1988; Yuen and Fried 1985).

Outlook to 1995

Comparisons of 1992-95 forecasts based only on spawner-recruit data not adjusted for historic errors suggested that the total number of sockeye salmon returning to Bristol Bay would be lower in 1992 and 1993 compared to 1994 and 1995 (Table 4). The higher forecasts for 1994 and 1995 are due to large predictions to Kvichak River. Predicted runs to Egegik River were similar for 1992-95 because spawning escapements are greater than previously recorded and were not used in a regression. Instead, the 1978-91 mean return to Egegik River was used. Runs to Ugashik River were predicted to be lowest in 1992 and highest in 1994. Rivers in Nushagak District had fairly high predictions in 1994-95, but lower predictions for 1992-93. Runs to Togiak River were predicted to be highest in 1993 and lowest in 1994. Annual returns to all river systems were predicted to be greater than desired spawning goals for all years examined.

Fried and Yuen (1987) and Fried et al. (1988) suggested that sockeye salmon returns after 1986 might be adversely affected by the onset of less favorable environmental conditions: cooler than average June air temperatures during the three years each brood year spent at sea (Figure 17). Although mean production was not expected to fall to the levels observed prior to 1978 (mean returns-per-spawner (RPS) 1965-77 = 2.0; range = 0.5 - 3.6), when large numbers of sockeye salmon were captured on the high seas by foreign vessels, production was also not anticipated to attain the extremely high levels observed during 1978-83 (mean RPS = 4.6; range = 3.8 - 5.7). Based on results of the analyses presented in this paper, we feel that sockeye salmon production from brood years contributing to returns in 1992-95 (mean predicted RPS = 2.8; range = 2.3 - 3.8) will be similar to the long-term

1965-91 average (mean RPS = 2.9); but slightly lower than the previous five year 1987-91 average (mean RPS = 3.6; range = 2.4 - 4.7).

However, as we cautioned in our last report (Cross et al. 1992), while a strong positive correlation (r = 0.618, significant at the 99% level,P > 0.01) was present between RPS and average temperature index (ATI) deviations for all available years, 1965-91, there have been departures from the expected relationship in seven out of the nine most recent years (Figure 17). RPS values for the 1984-1986 return years were below average when corresponding ATI values were above average; RPS values for the 1987 and 1989 return years were above average when the corresponding ATI values were either below average or average. These occurrences suggest that the formerly strong relationship between RPS and ATI deviations appears to be deteriorating. Either very large deviations in ATI, in excess of 1.5 - 2.0 F° as were observed during 1973-82, must occur before sockeye salmon production is affected, or the correlation between ATI and RPS was spurious.

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Table 1. Comparison of preliminary forecasts, estimated forecast errors, and adjusted forecasts for 1992 combined eastside and westside Bristol Bay rivers.

Data Base	Original 1992 Forecast	Method of Modeling	Estimated Error 1992[a]	Adjusted 1992 Forecast
	Millions of Sockeye Salmon			
Eastside- All Data	19.2	Linear Regress	-19.2	38.4
Eastside- All Data	19.2	Polynomial Regress	-21.5	40.7
Eastside- All Data	19.2	Time Series AR(1)	-19.4	38.6
Eastside- Recent Data	25.2	84-91 Average Error	-8.8	34.0
Westside- All Data	4.5	Linear Regress	-3.0	7.5
Westside- All Data	4.5	Polynomial Regress	-0.9	5.4
Westside- All Data	4.5	84-91 Average Error	-1.1	5.6
Westside- Recent Data	5.9	84-91 Average Error	+1.2	4.7

[a] Error = (predicted - actual).

Table 2. Forecasted production, spawning escapement goals, and total projected harvests of major age classes of sockeye salmon returning to Bristol Bay, Alaska, river systems in 1992 based on results of the Mixed Data method adjusted by the 1984-91 average percent error.

	Numbers of sockeye salmon (thousands)							
	Forecasted Production by Age Class							
District River	1.2	2.2	1.3	2.3	Other[a]	Total	Spawning Goal	Total Harvest
NAKNEK-KVICHAK:								
Kvichak	3,451	6,738	2,343	424		12,956	6,000	6,956
Branch	250	46	254	28		578	185	393
Naknek	602	866	1,586	1,444		4,498	1,000	3,498
Total	4,303	7,650	4,183	1,896		18,032	7,185	10,847
EGEGIK	961	5,998	2,078	2,339		11,376	1,000	10,376
UGASHIK	1,078	1,699	1,087	744		4,608	700	3,908
NUSHAGAK:[b]								
Wood	1,006	139	1,524	68		2,737	1,000	1,737
Igushik	117	38	516	50		721	200	521
Nushagak-Mulchatna	91	3	664	8	722	1,488	550	938
Total	1,214	180	2,704	126	722	4,946	1,750	3,196
TOGIAK[c]	120	35	437	44		636	150	486
BRISTOL BAY	7,676	15,562	10,489	5,149	722	39,598	10,785	28,813

[a] Other age classes include zero freshwater ages (0.2, 0.3, 0.4) which are only forecasted for Nushagak-Mulchatna River.

[b] Forecast for Snake River system was not included (1971-1991 average escapement was 15,000).

[c] Forecasts for Kulukak, Kanik, Osviak, and Matogak River systems were not included. These systems may contribute an additional 102,000 (1978-1991 mean return) to Togiak District.

Table 3. Projected commercial harvests of sockeye salmon returning to Bristol Bay, Alaska, river systems in 1992 based on results of the Mixed Data method adjusted by the 1984-91 average percent error.

	Numbers of sockeye salmon (thousands)				
			Bristol Bay		
District: System	Forecasted Total Production	Shumagin Islands-S. Unimak Harvest[a]	Total Run	Spawning Goal	Harvest
NAKNEK-KVICHAK:					
Kvichak	12,956	782	12,174	6,000	6,174
Branch	578	35	543	185	358
Naknek	4,498	272	4,226	1,000	3,226
Total	18,032	1,089	16,943	7,185	9,758
EGEGIK	11,376	687	10,689	1,000	9,689
UGASHIK	4,608	278	4,330	700	3,630
NUSHAGAK:					
Wood	2,737	165	2,572	1,000	1,572
Igushik	721	44	677	200	477
Nushagak-Mulchatna	1,488	90	1,398	550	848
Total	4,946	299	4,647	1,750	2,897
TOGIAK	636	38	598	150	448
TOTAL BRISTOL BAY	39,598	2,391	37,207	10,785	26,422

[a] Guideline harvest calculated as 8.3% of projected Bristol Bay harvest. Numbers were apportioned among river systems based on proportions in the forecast of total production.

Table 4. Preliminary forecasts of sockeye salmon returns to Bristol Bay, Alaska, 1992-1995, based on spawner-recruit data only, and not adjusted for historic forecast errors.

DISTRICT: River System	Number of Sockeye Salmon (thousands)			
	1992	1993	1994	1995
NAKNEK-KVICHAK:				
Kvichak	10,788	10,400	14,826	12,660
Branch	455	437	433	437
Naknek	3,405	3,103	3,539	4,785
Total	14,648	13,940	18,798	17,882
EGEGIK	7,610	6,684	6,883	6,883
UGASHIK	2,883	3,360	4,770	4,252
NUSHAGAK:				
Wood	1,933	2,038	2,059	2,102
Igushik	521	540	734	708
Nushagak-Mulchatna	1,487	1,487	1,487	1,487
Total	3,941	4,065	4,280	4,297
TOGIAK	475	518	344	441
TOTAL BRISTOL BAY	29,557	28,567	35,075	33,755

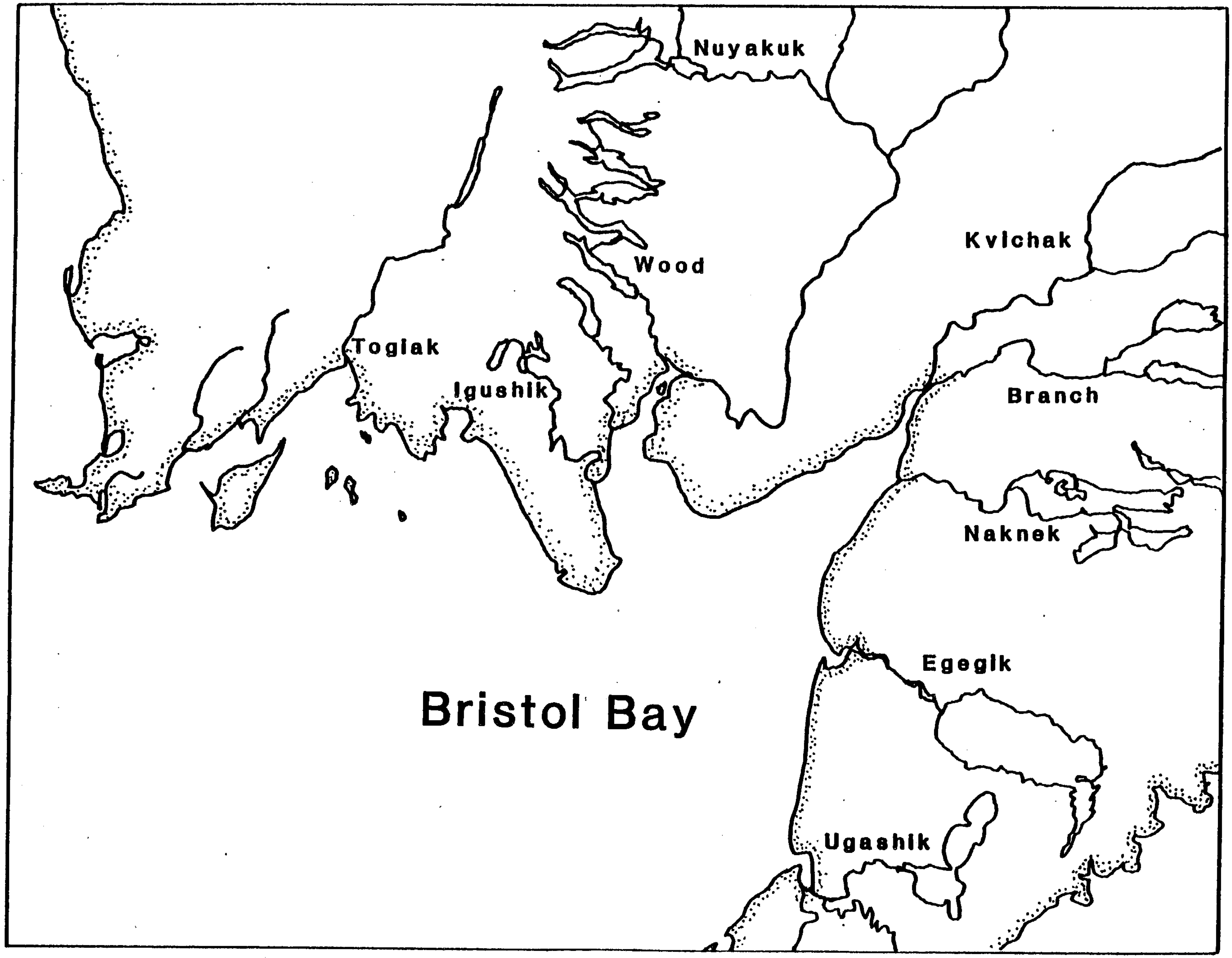

Figure 1. Map of Bristol Bay, Alaska showing major rivers.

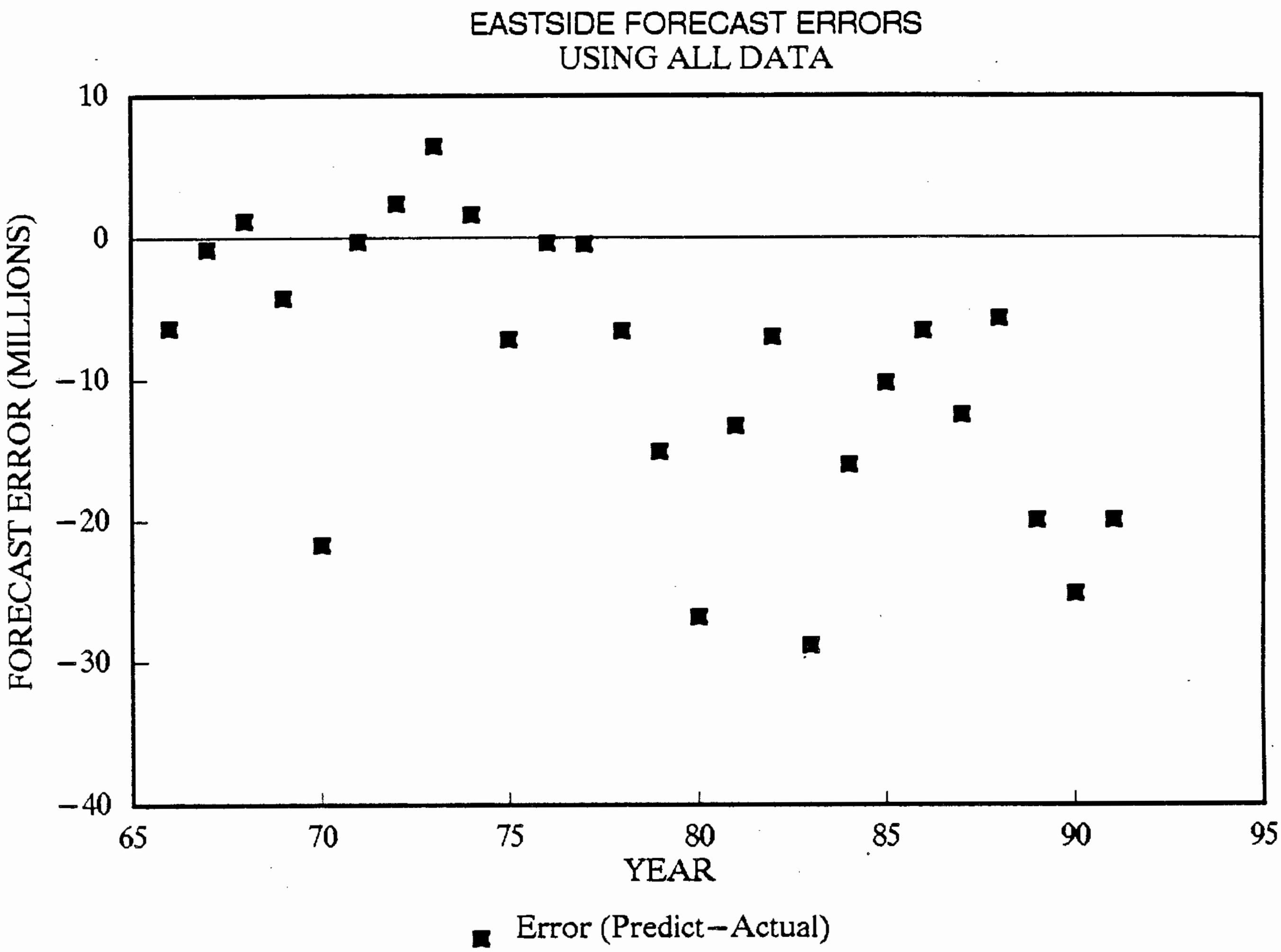

Figure 2. Errors (predicted run - actual run) of combined eastside Bristol Bay forecasts made with All Data for 1965-1991.

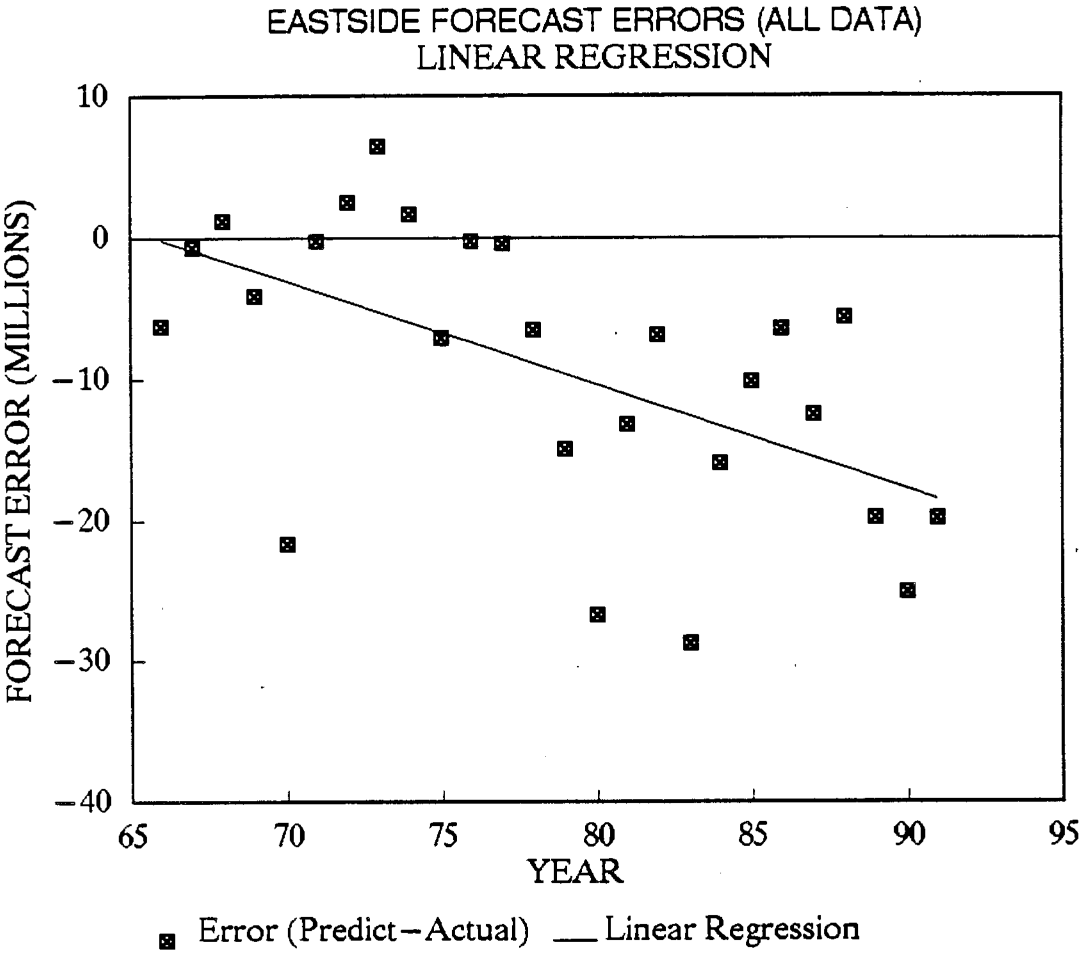

Figure 3. Linear regression model of errors (predicted run - actual run) of combined eastside Bristol Bay forecasts made with All Data for 1965-1991.

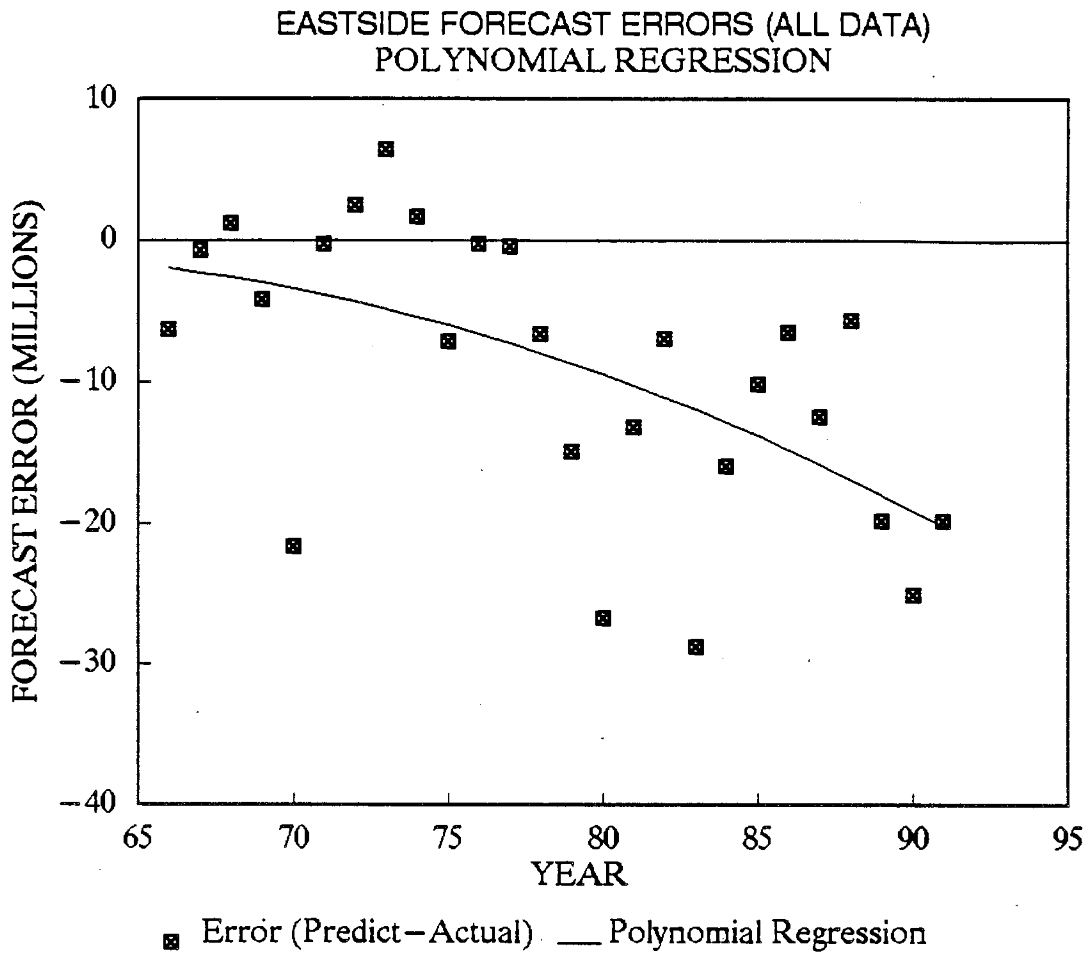

Figure 4. Polynomial regression model of errors (predicted run - actual run) of combined eastside Bristol Bay forecasts made with All Data for 1965-1991.

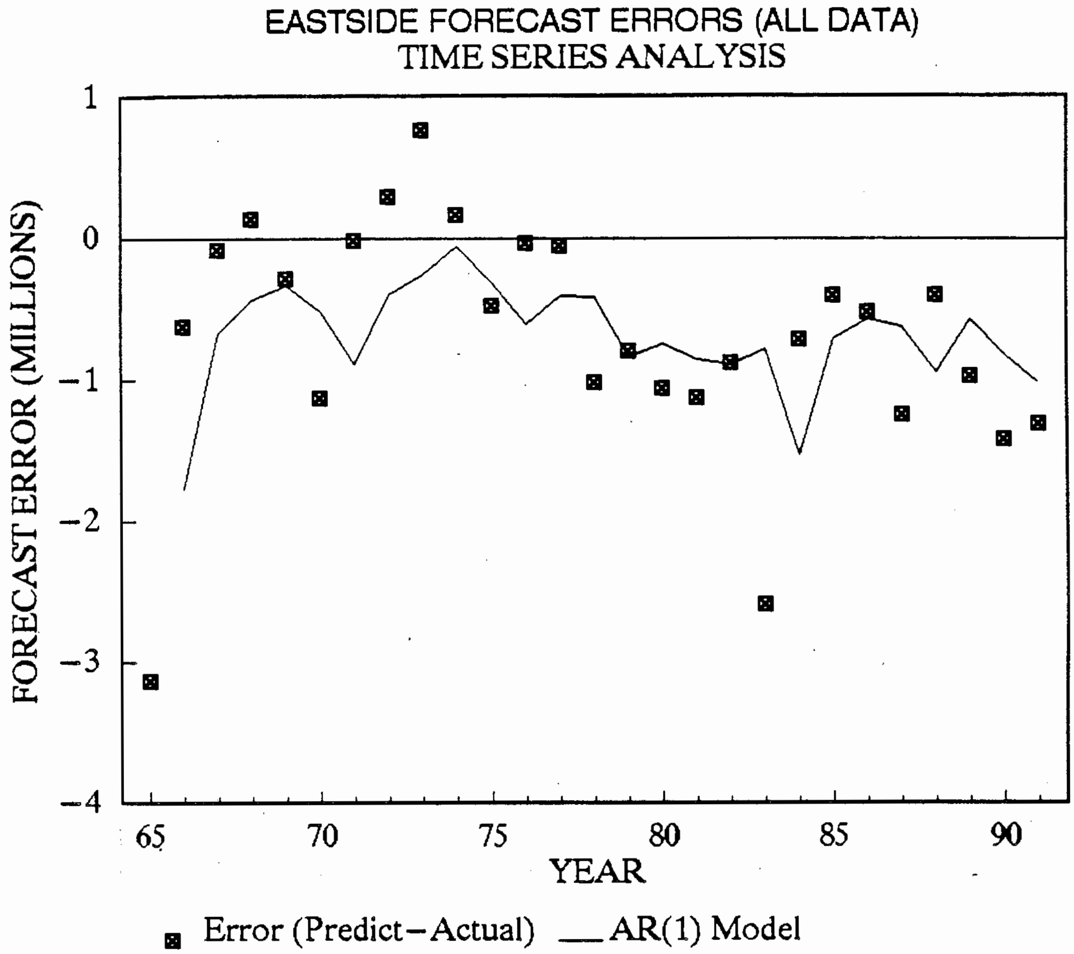

Figure 5. Time series model of errors (predicted run - actual run) of combined eastside Bristol Bay forecasts made with All Data for 1965-1991.

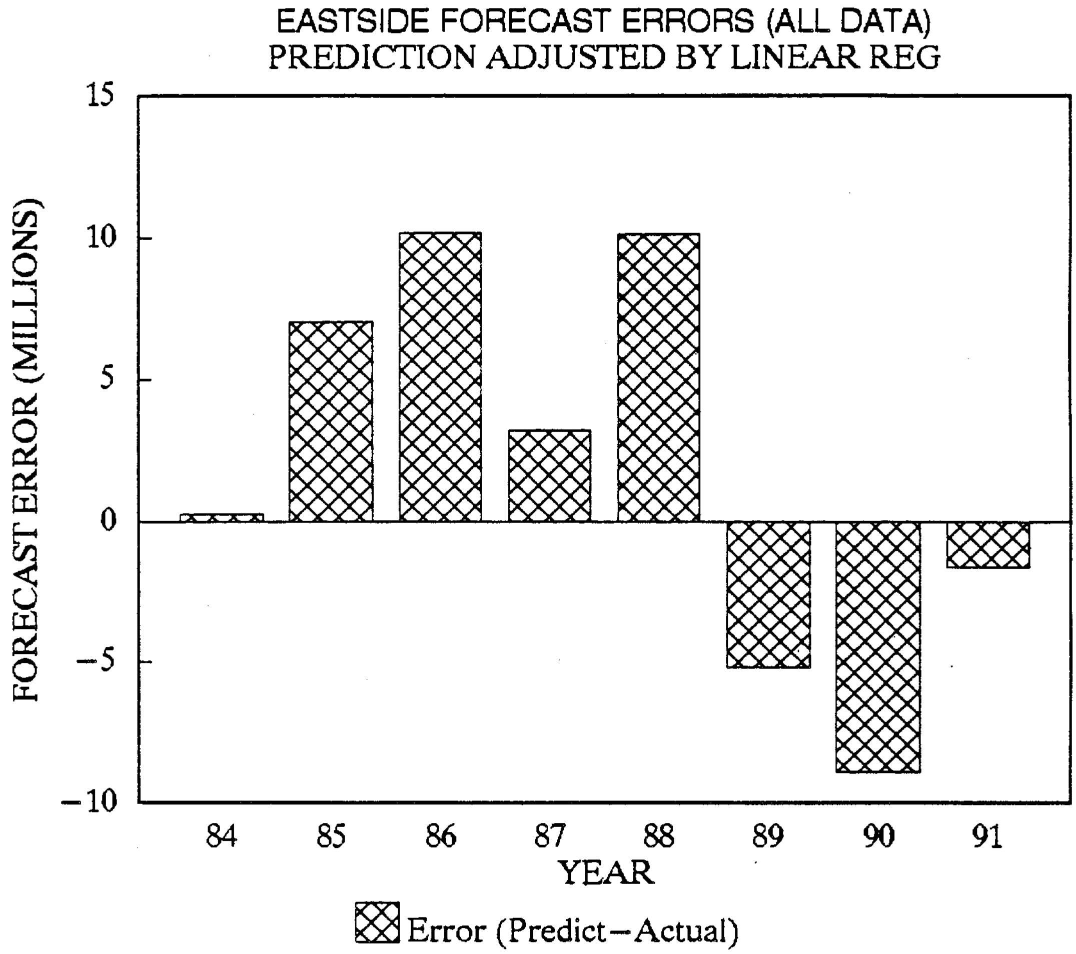

Figure 6. Errors (predicted run - actual run) of combined eastside Bristol Bay forecasts made with All Data and adjusted with an estimate of error from linear regression model, 1984-1991.

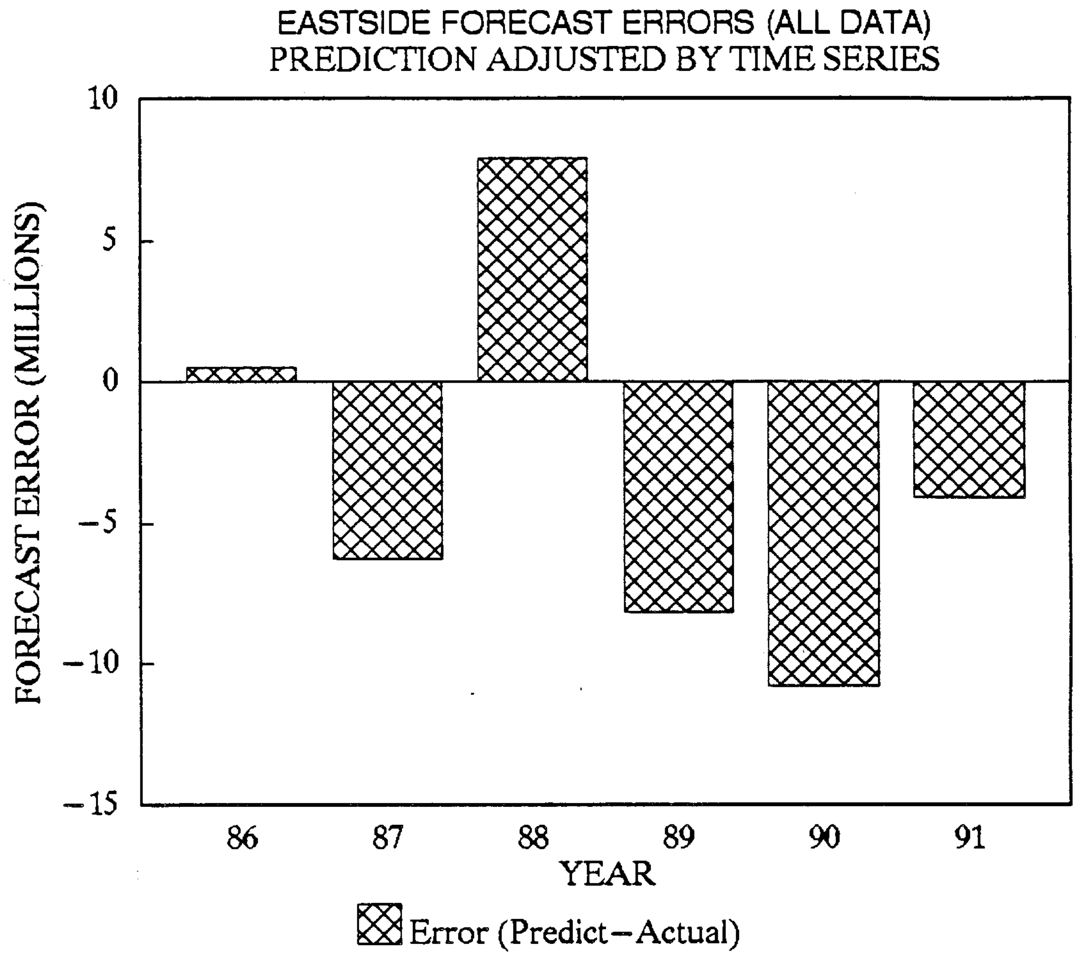

Figure 7. Errors (predicted run - actual run) of combined eastside Bristol Bay forecasts made with All Data and adjusted with an estimate of error from time series model, 1986-1991.

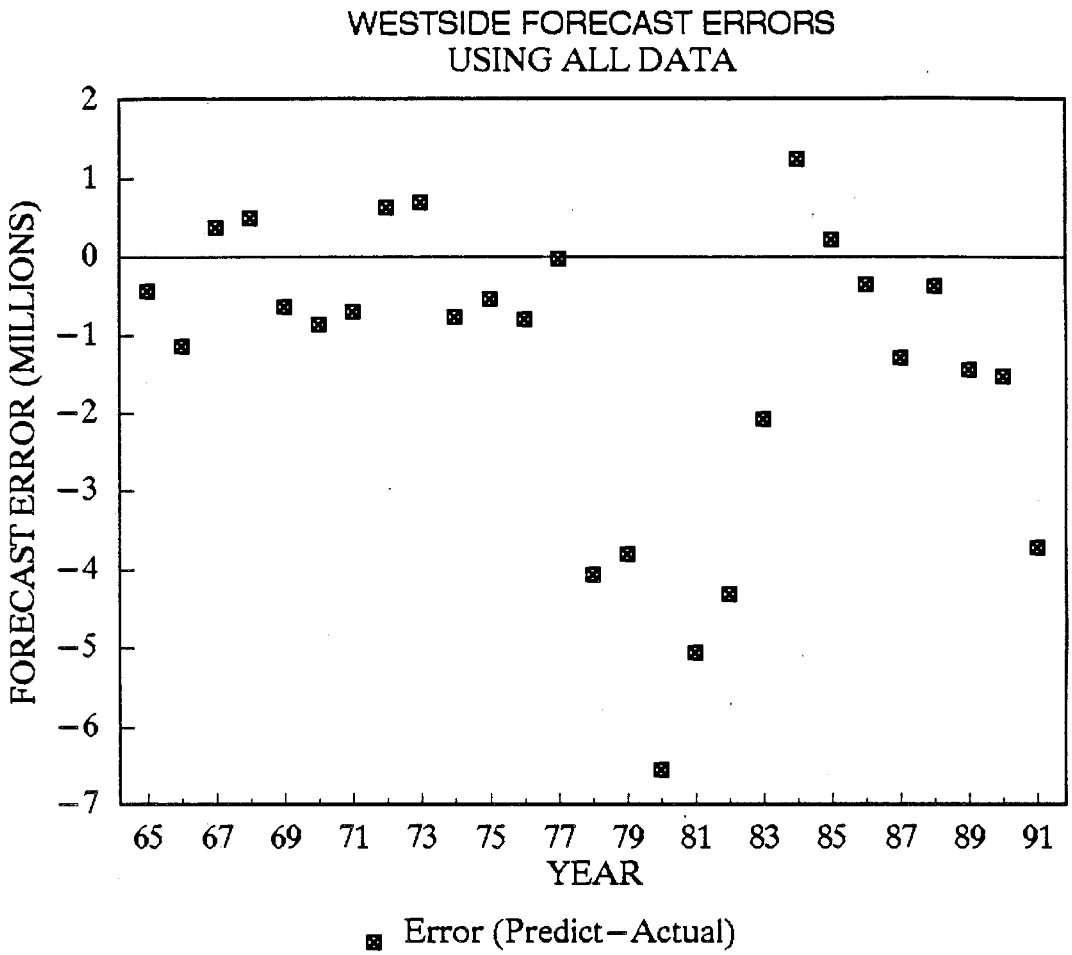

Figure 8. Errors (predicted run - actual run) of combined westside Bristol Bay forecasts made with All Data for 1965-1991.

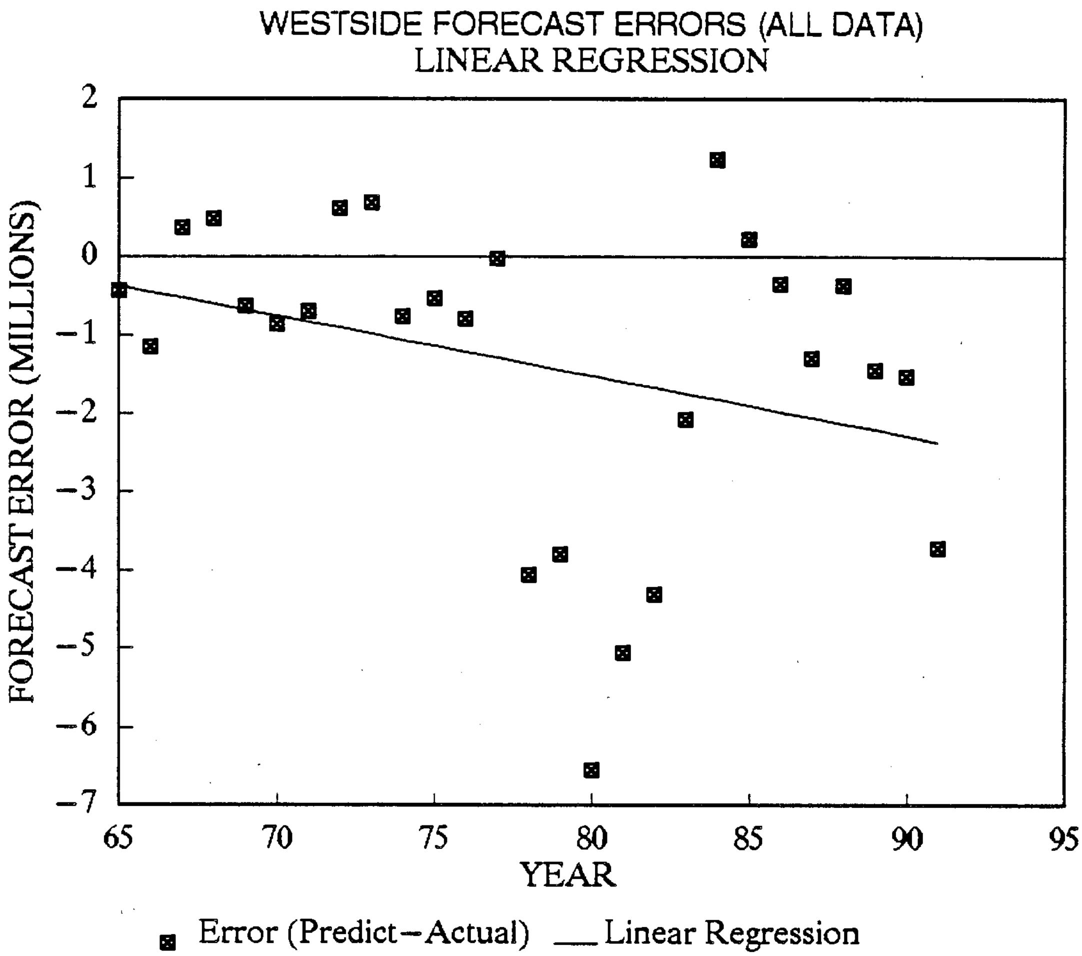

Figure 9. Linear regression model of errors (predicted run - actual run) of combined westside Bristol Bay forecasts made with All Data for 1965–1991.

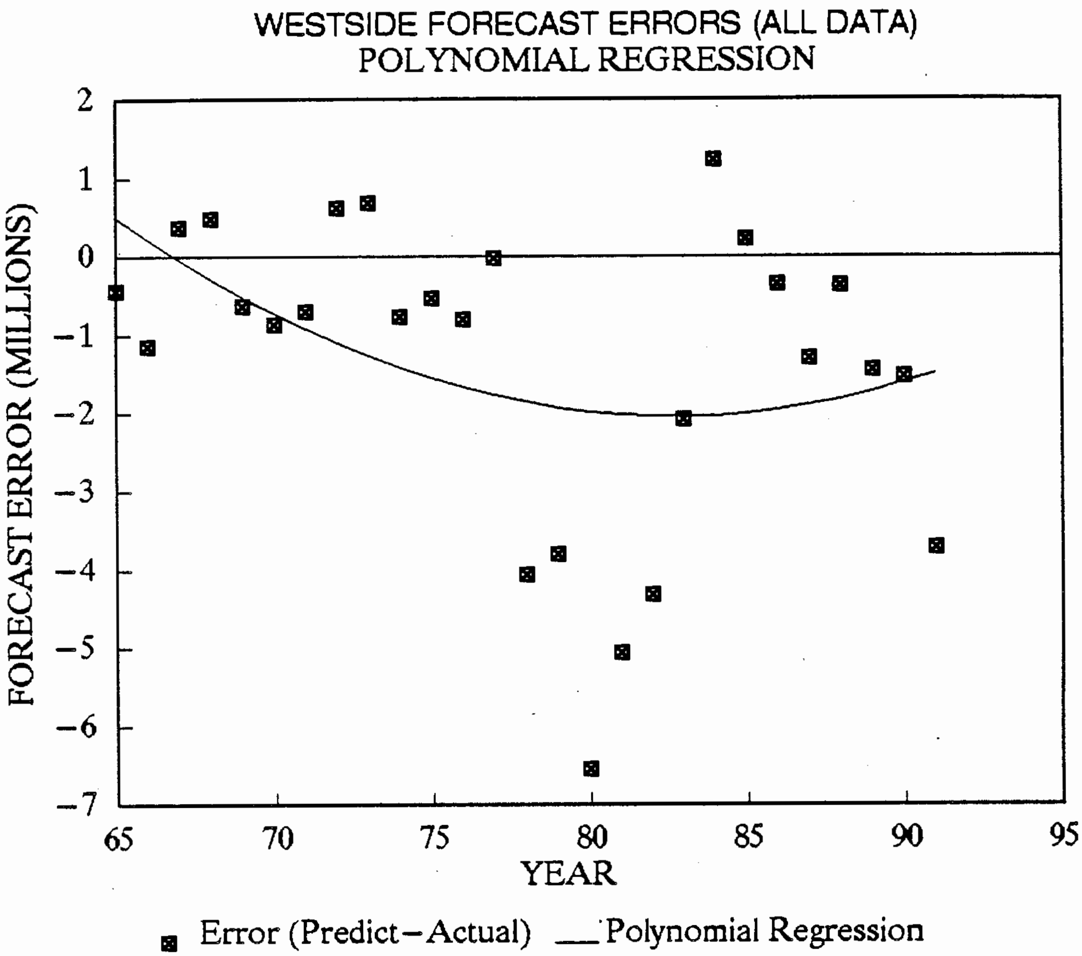

Figure 10. Polynomial regression model of errors (predicted run - actual run) of combined westside Bristol Bay forecasts made with All Data for 1965-1991.

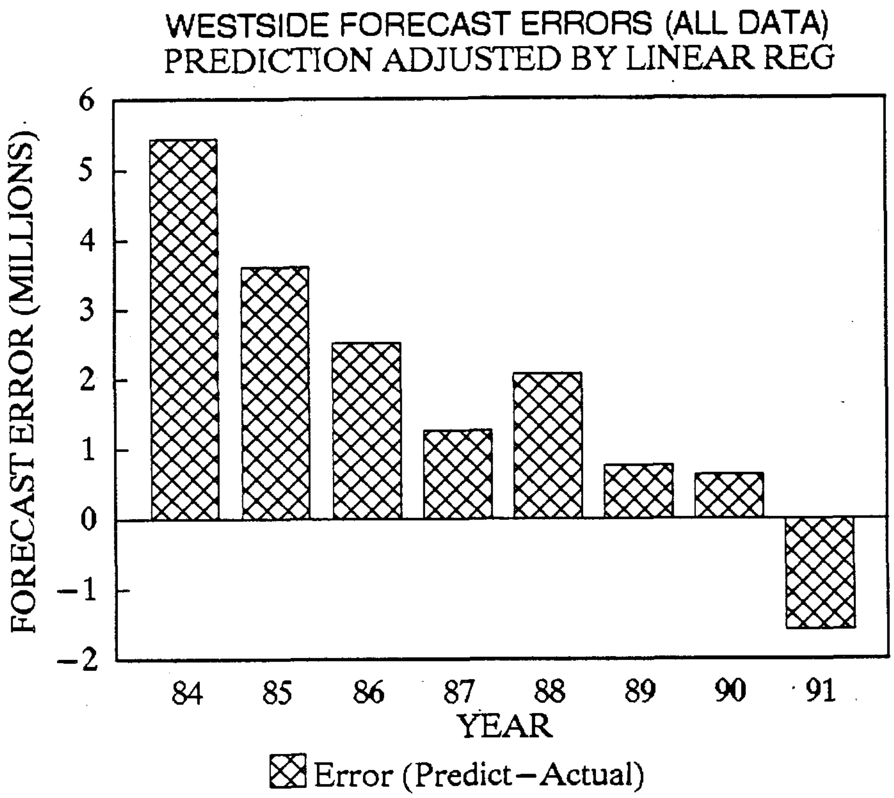

Figure 11. Errors (predicted run - actual run) of combined westside Bristol Bay forecasts made with All Data and adjusted with an estimate of error from linear regression model, 1984-1991.

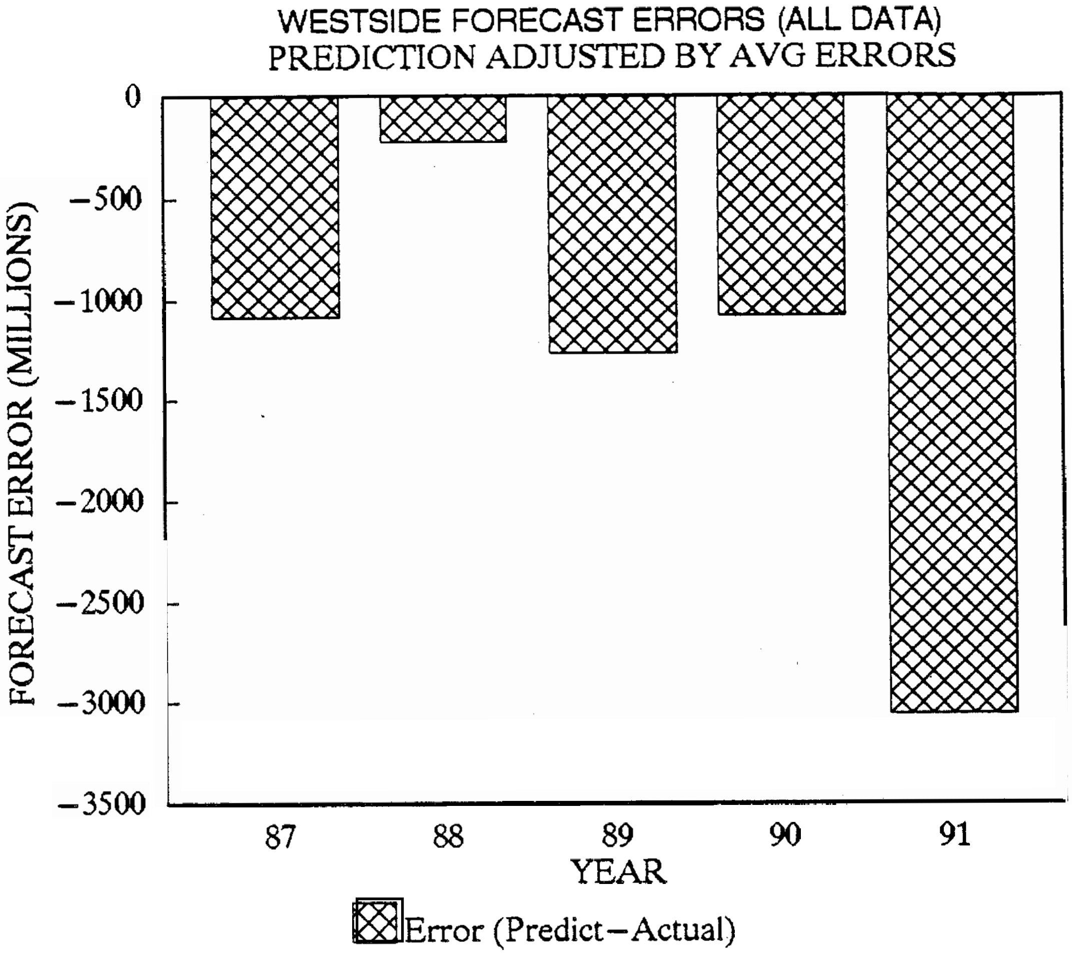

Figure 12. Errors (predicted run - actual run) of combined westside Bristol Bay forecasts made with All Data and adjusted with the average percent error, 1987-1991.

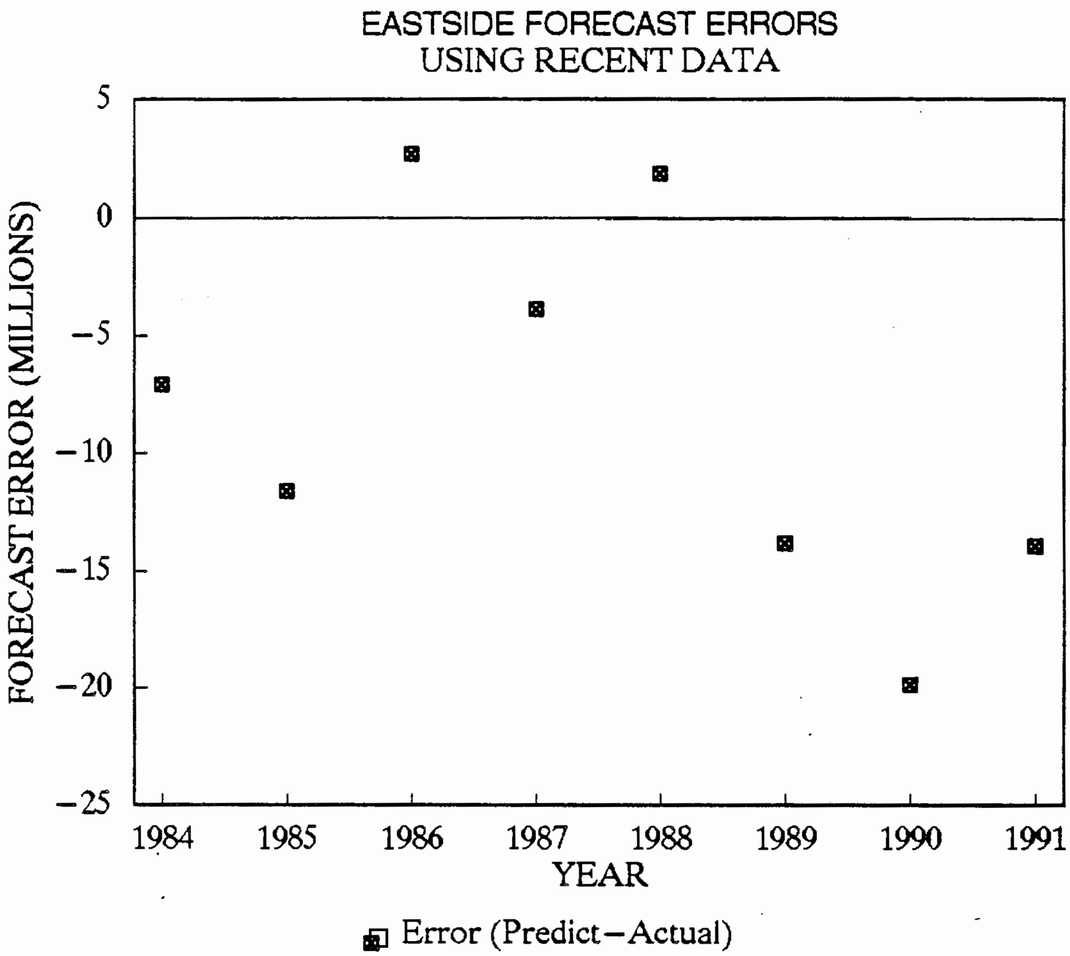

Figure 13. Errors (predicted run - actual run) of combined eastside Bristol Bay forecasts made with Recent Data for 1984-1991.

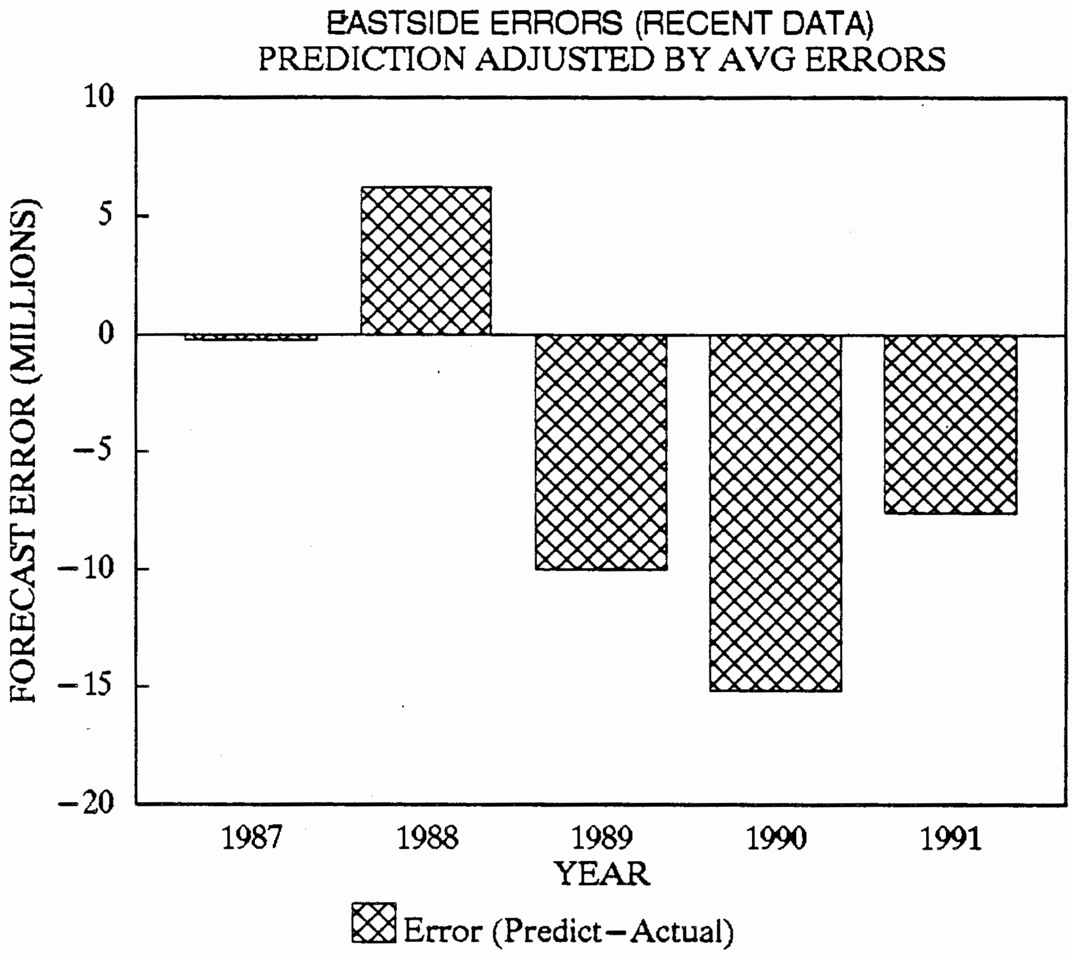

Figure 14. Errors (predicted run - actual run) of combined eastside Bristol Bay forecasts made with Recent Data and adjusted with the average percent error, 1987-1991.

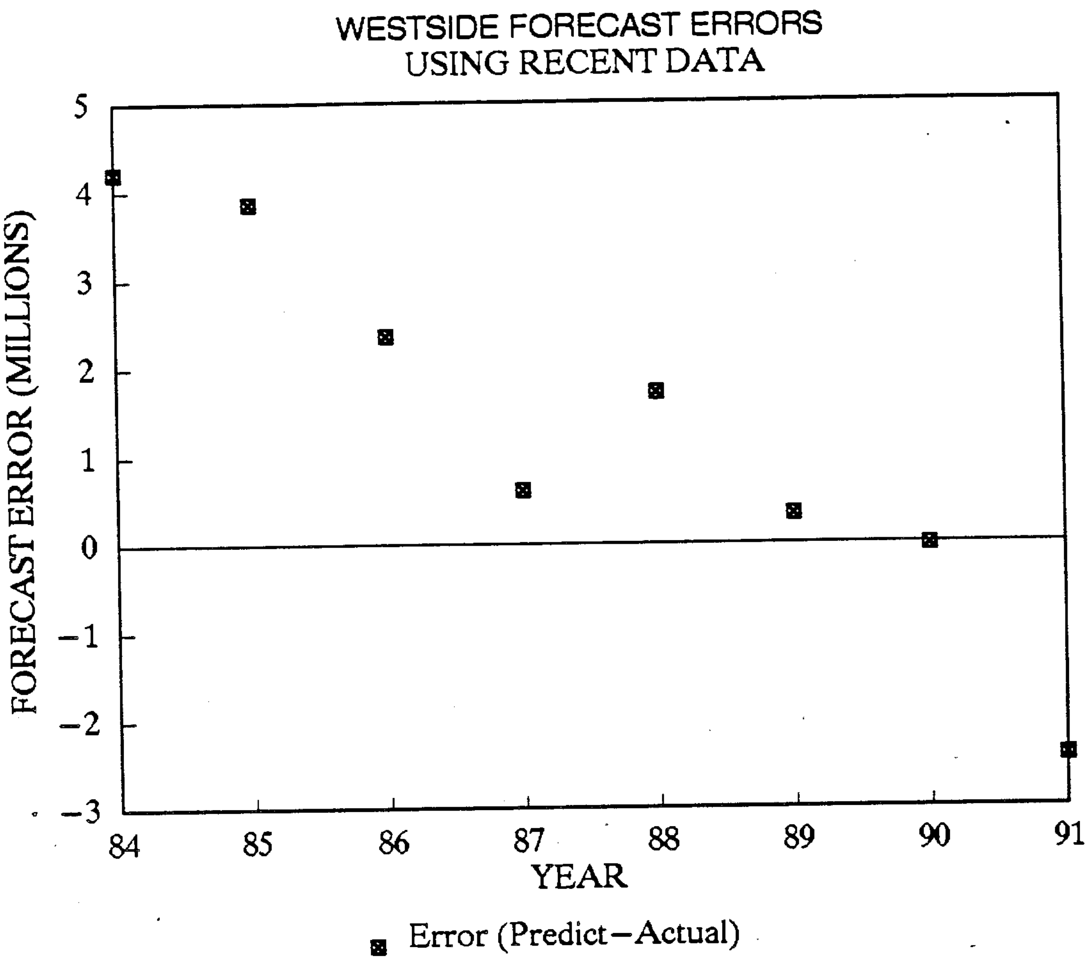

Figure 15. Errors (predicted run - actual run) of combined westside Bristol Bay forecasts made with Recent Data for 1984-1991.

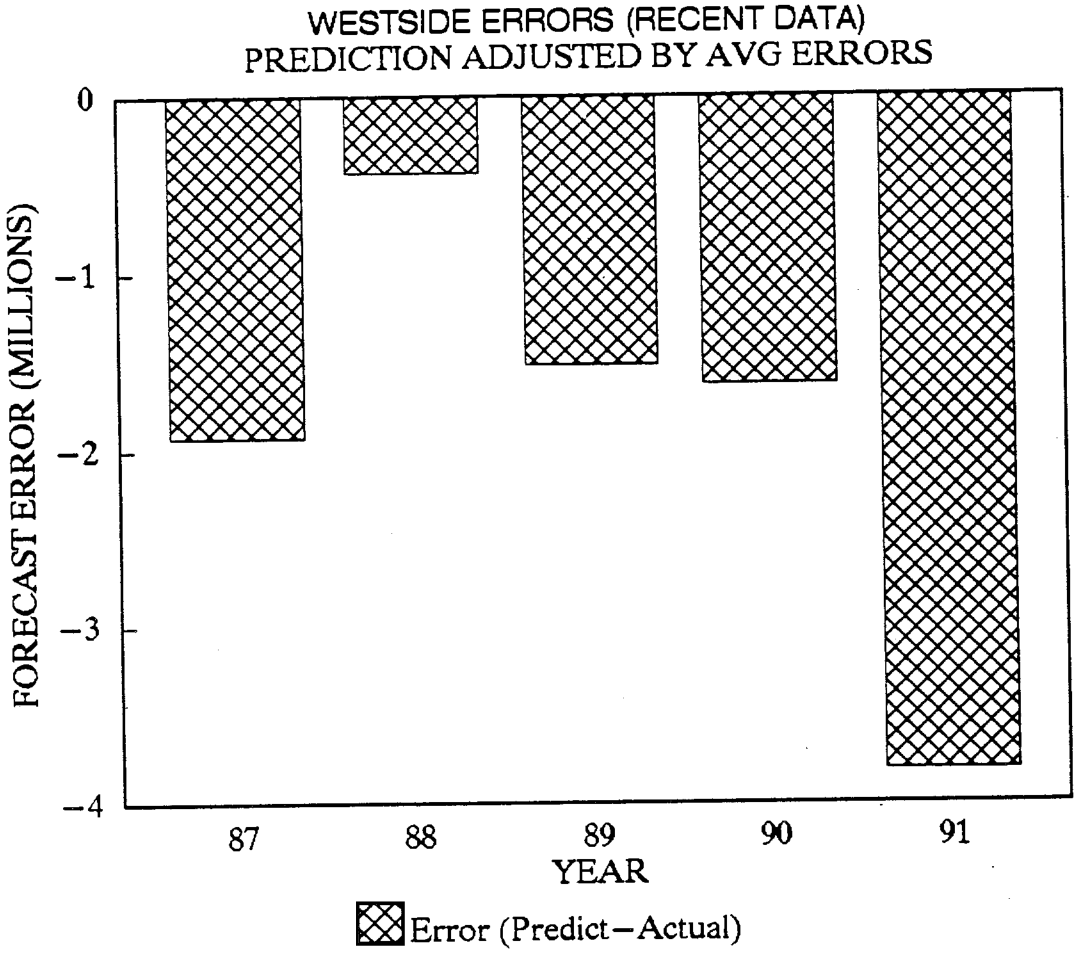

Figure 16. Errors (predicted run - actual run) of combined westside Bristol Bay forecasts made with Recent Data and adjusted with the average percent error, 1987–1991.

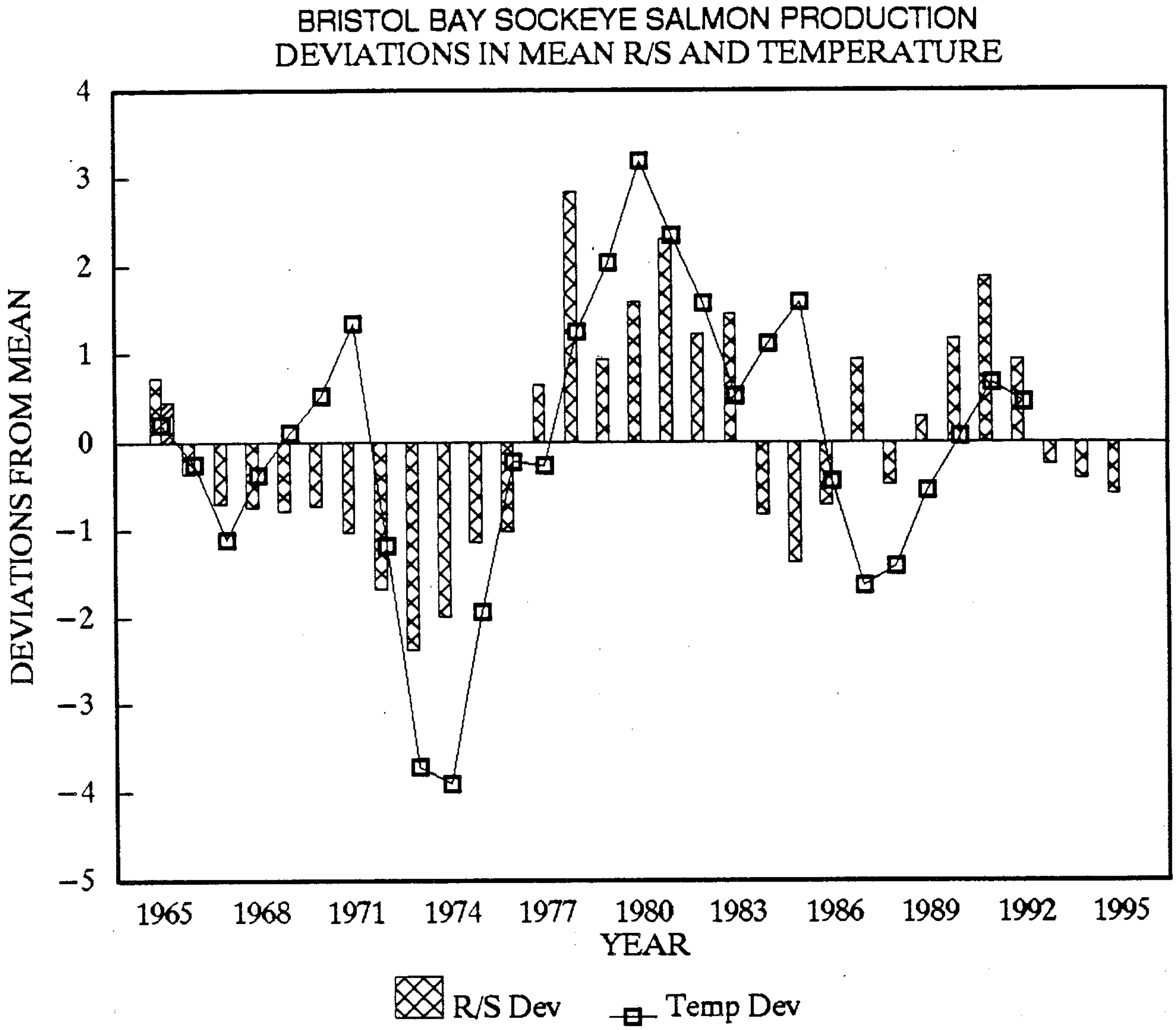

Figure 17. Annual deviations from the mean number of returning Bristol Bay, Alaska, sockeye salmon produced per spawner (bar chart) and mean Cold Bay, Alaska, June air temperature (line chart), 1965–1991. Deviations from forecasted return per spawner values are shown for 1992–1995 (solid bars).

APPENDIX A: HISTORIC SOCKEYE FORECASTS AND RETURNS

Appendix A.1. Preseason forecasts of sockeye salmon returns to Bristol Bay, Alaska, 1961-1991, issued by the Alaska Department of Fish and Game.

Year	Forecast (millions)	Actual Return (millions)		Percent Error[b]
		Inshore	Total[a]	
1961	43.6	18.1	24.5	78.0
1962	19.6	10.4	11.7	67.5
1963	8.6	6.9	8.0	7.5
1964	17.4	10.9	11.5	51.3
1965	27.8	53.1	60.8	-54.3
1966	31.3	17.5	20.0	56.5
1967	13.7	10.3	11.5	19.1
1968	10.4	8.0	9.4	10.6
1969	21.3	19.0	21.9	-2.7
1970	55.8	39.4	45.0	24.0
1971	15.2	15.8	18.3	-16.9
1972	9.7	5.4	7.2	34.7
1973	6.2	2.4	3.5	77.1
1974	5.0	10.9	11.5	-56.5
1975	12.0	24.2	25.8	-53.5
1976	12.0	11.5	12.8	-6.3
1977	8.4	9.7	10.7	-21.5
1978	11.5	19.8	20.8	-44.7
1979	22.7	39.8	40.9	-44.5
1980	54.5	62.4	66.2	-17.7
1981	26.7	34.5	37.1	-28.0
1982	34.6	22.1	24.7	40.1
1983	33.4	45.8	48.0	-30.4
1984	31.1	41.0	42.6	-27.0
1985	35.0	36.6	38.5	-9.1
1986	22.5	23.7	24.4	-7.8
1987	16.5	27.3	28.3	-41.7
1988	28.8	23.2	24.0	20.0
1989	30.4	43.9	45.7	-33.5
1990	26.7	47.6	49.0	-45.5
1991	31.9	42.2	43.8	-27.2

[a] Includes foreign high seas and domestic Shumagin Islands-South Unimak catches for 1961-1991.

[b] Percent error calculated as:
(forecast - actual total return) / actual total return x 100.

APPENDIX B: HINDCAST ERRORS

Appendix B.1. Annual percent errors, mean percent errors (MPE), and mean absolute percent errors (MAPE) for hindcasts of total sockeye salmon returns to Bristol Bay, Alaska, river systems, 1984-91, based on All Data (1956-91) or Recent Data (1978-91).

	Percent Errors[a]											
Year	Kvichak	Branch	Naknek	Egegik	Ugashik	Wood	Igushik	Nuyakuk	Togiak	Combined East	Combined West	Total
						ALL DATA FORECASTS						
1984	-40.0	-32.7	-29.4	-49.1	-44.4	-12.2	73.5	23.9	0.4	-41.1	7.8	-36.5
1985	1.3	-9.5	-21.0	-58.9	-56.9	5.1	-33.5	-4.6	-20.5	-29.8	-5.7	-27.7
1986	126.3	-52.6	-32.0	-54.7	-67.8	-3.5	-36.2	-26.8	-4.4	-34.7	-18.1	-31.3
1987	-78.4	-13.4	-15.5	-43.0	-47.8	-35.0	-18.9	37.7	-24.0	-55.7	-22.0	-49.8
1988	-9.5	-13.0	13.5	-54.5	-17.0	9.9	13.5	42.3	-56.0	-27.3	-1.3	-23.0
1989	-48.5	-48.0	-18.4	-61.4	-47.4	-24.6	-64.5	-37.0	81.0	-49.4	-33.5	-47.5
1990	-55.6	-47.6	-65.1	-61.5	-50.2	-29.6	-51.1	-52.2	-11.9	-58.8	-39.6	-56.3
1991	-49.1	-49.2	-68.1	-41.1	-75.9	-38.0	-75.9	-34.8	-52.3	-56.8	-49.7	-55.4
84-91 MPE	-19.2	-33.2	-29.5	-53.0	-50.9	-16.0	-24.1	-6.4	-11.0	-44.2	-20.3	-40.9
84-91 MAPE	51.1	33.2	39.4	53.0	50.9	19.7	45.9	32.4	31.3	44.2	22.2	40.9
						RECENT DATA FORECASTS						
1984	-21.7	-4.1	47.4	-34.0	-27.7	105.7	355.7	196.4	80.2	-18.7	152.9	-2.5
1985	-29.6	83.7	2.9	-44.0	-49.1	141.0	227.6	34.8	92.4	-33.2	124.4	-19.6
1986	287.6	-0.7	3.7	-36.1	-15.7	93.1	59.1	23.5	28.5	14.3	56.0	23.0
1987	-55.9	9.8	68.9	-27.4	59.2	-3.7	98.1	248.4	14.6	-17.5	45.2	-6.6
1988	33.1	28.6	35.4	-28.5	51.9	68.4	181.0	177.0	-26.9	9.4	74.3	20.1
1989	-37.6	-33.5	0.9	-44.0	-24.3	4.4	-24.1	-2.3	287.7	-34.4	5.5	-29.7
1990	-47.5	-26.4	-55.7	-53.4	9.6	-4.6	0.5	-16.1	23.6	-46.7	-5.1	-41.3
1991	-25.6	-37.5	-52.4	-33.2	-50.2	-21.6	-53.4	-12.8	-35.4	-39.9	-30.3	-38.0
84-91 MPE	12.9	2.5	6.4	-37.6	-5.8	47.9	105.6	81.1	58.1	-20.8	52.9	-11.8
84-91 MAPE	67.3	28.0	33.4	37.6	36.0	55.3	124.9	88.9	73.7	26.8	61.7	22.6

[a] Percent error calculated as:
(forecast - actual total return) / actual total return x 100.

Appendix B.2. Annual percent errors, mean percent errors (MPE), and mean absolute percent errors (MAPE) for hindcasts of total sockeye salmon returns to Bristol Bay, Alaska, river systems, 1984-1991, based on the Mixed Data method[a].

	Percent Errors[b]									
Year	Kvichak	Branch	Naknek	Egegik	Ugashik	Wood	Igushik	Nuyakuk	Togiak	Total
1984	-21.7	-4.1	47.4	-34.0	-27.7	-12.2	73.5	23.9	0.4	-16.2
1985	-29.6	83.7	2.9	-44.0	-49.1	5.1	-33.5	-4.6	-20.5	-30.8
1986	287.6	-0.7	3.7	-36.1	-15.7	-3.5	-36.2	-26.8	-4.4	7.6
1987	-55.9	9.8	68.9	-27.4	59.2	-35.0	-18.9	37.7	-24.0	-18.3
1988	33.1	28.6	35.4	-28.5	51.9	9.9	13.5	42.3	-56.0	7.6
1989	-37.6	-33.5	0.9	-44.0	-24.3	-24.6	-64.5	-37.0	81.0	-34.3
1990	-47.5	-26.4	-55.7	-53.4	9.6	-29.6	-51.1	-52.2	-11.9	-45.8
1991	-25.6	-37.5	-52.4	-33.2	-50.2	-38.0	-75.9	-34.8	-52.3	-41.8
84-91 MPE	12.9	2.5	6.4	-37.6	-5.8	-16.0	-24.1	-6.4	-11.0	-21.5
84-91 MAPE	67.3	28.0	33.4	37.6	36.0	19.7	45.9	32.4	31.3	25.3

[a] Recent Data (1978-91) used for Kvichak, Branch, Naknek, Egegik, and Ugashik River systems; All Data (1956-91) used for other river systems:

[b] Percent error calculated as:
(forecast - actual total return) / actual total return x 100.

APPENDIX C: UNADJUSTED RIVER SYSTEM FORECASTS

Appendix C.1. Forecasted returns of major age classes of sockeye salmon to the Kvichak River system, Bristol Bay, Alaska, in 1992 based on linear regression models using spawner-recruit, sibling, and smolt data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	4,065	2,578	2.5	14
2.2	6,065	5,823	0.1	14
1.3	6,065	2,086	0.5	14
2.3	1,179	301	5.0	14
	Total	10,788		

Sibling Data

Age Class	Sibling Return in 1991 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	5	8[a]	NS	8
2.2	30	5,634	0.1	11
1.3	4,208	1,443	1.0	13
2.3	1,425	392	2.5	13
	Total	7,477		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	46,569	2,539	5.0	14
2.2	41,434	3,530	0.1	14
1.3	146,603	1,682	10.0	13
2.3	6,830	250	2.5	13
	Total	8,001		

[a] Estimate not used; regression model not significant at 25% level ($P > 0.25$).

Appendix C.2. Forecasted returns of major age classes of sockeye salmon to the Branch River system, Bristol Bay, Alaska, in 1992 based on linear regression models using spawner-recruit and sibling data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	195	212	5.0	14
2.2	154	34	25.0	13
1.3	154	188	2.5	14
2.3	230	11[a]	NS	14
	Total	445		

Sibling Data

Age Class	Sibling Return in 1991 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1	158	25.0	11
2.2	0	[b]	NS	3
1.3	158	158[a]	NS	13
2.3	197	25[c]	25.0	12
	Total	341		

[a] Estimate not used; regression model not significant at 25% level (P>0.25).

[b] Estimate not made; zero age-1.1 sockeye salmon returned to Branch River in 1991.

[c] Estimate not used; age-2.2 sibling return greater than past values used to build model (4 thousand - 91 thousand).

Appendix C.3. Forecasted returns of major age classes of sockeye salmon to the Naknek River system, Bristol Bay, Alaska, in 1992 based on linear regression models using spawner-recruit and sibling data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1,038	446	25.0	14
2.2	1,062	642	25.0	14
1.3	1,062	1,259	10.0	14
2.3	1,978	1,058	5.0	14
	Total	3,405		

Sibling Data

Age Class	Sibling Return in 1991 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[a]	NS	11
2.2	3	490[b]	NS	11
1.3	337	1,093	2.5	13
2.3	1,308	1,084	1.0	13
	Total	2,667		

[a] Estimate not made; zero age-1.1 sockeye salmon returned to Naknek River in 1991.

[b] Estimate not used; regression model not significant at 25% level (P>0.25).

Appendix C.4. Forecasted returns of major age classes of sockeye salmon to the Egegik River system, Bristol Bay, Alaska, in 1992 based on linear regression models using spawner-recruit, sibling, and smolt data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1,613	291[a]	5.0	14
2.2	1,273	4,163	2.5	14
1.3	1,273	889[b]	NS	14
2.3	1,151	1,380	25.0	14
	Total	6,723		

Sibling Data

Age Class	Sibling Return in 1991 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1	839	25.0	9
2.2	63	4,731	5.0	13
1.3	892	1,541	0.1	13
2.3	4,019	1,602	5.0	13
	Total	8,713		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	3,795	586	5.0	8
2.2	52,299	5,275[c]	25.0	8
1.3	72,458	2,935[c]	5.0	7
2.3	27,347	2,221	10.0	7
	Total	11,017		

[a] Estimate not used; spawning escapement greater than past values used to build model (328 thousand - 1,275 thousand).

[b] Estimate not used; regression model not significant at 25% level (P>0.25).

[c] Estimate not used; age-1. and age-2. smolt production greater than past values used to build model (age-1.= 2,242 thousand - 54,586 thousand; age-2.= 11,435 thousand - 45,387 thousand).

Appendix C.5. Forecasted returns of major age classes of sockeye salmon to the Ugashik River system, Bristol Bay, Alaska, in 1992 based on linear regression models using spawner-recruit, sibling, and smolt data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	643	623	2.5	14
2.2	669	1,065	1.0	14
1.3	669	672	0.5	14
2.3	1,001	523	0.1	14
	Total	2,883		

Sibling Data

Age Class	Sibling Return in 1991 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1	975	2.5	10
2.2	10	1,455	10.0	12
1.3	838	940	0.1	13
2.3	1,935	581	0.1	13
	Total	3,951		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	14,837	184[a]	NS	7
2.2	38,789	1,611[a]	NS	7
1.3	88,999	1,867[a]	NS	6
2.3	34,657	932[a]	NS	6
	Total	4,594		

[a] Estimate not used; regression model not significant at 25% level ($P>0.25$).

Appendix C.6. Forecasted returns of major age classes of sockeye salmon to the Wood River system, Bristol Bay, Alaska, in 1992 based on linear regression models using spawner-recruit, sibling, and smolt data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	867	733	0.1	32
2.2	1,337	111	5.0	31
1.3	1,337	1,037	0.1	31
2.3	819	52	10.0	28
	Total	1,933		

Sibling Data

Age Class	Sibling Return in 1991 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	1	764	1.0	22
2.2	<1	93	2.5	12
1.3	1,417	934	5.0	35
2.3	72	46	0.1	33
	Total	1,837		

Smolt Data

Age Class	Smolt Production (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	27,793	715	0.5	15
2.2	453	10[a]	0.1	15
1.3	37,653	1,381	2.5	14
2.3	3,574	51	25.0	14
	Total	2,157		

[a] Estimate not used; age-2. smolt production less than past values used to build the models (age-2. smolt 598 thousand - 33,197 thousand)

Appendix C.7. Forecasted returns of major age classes of sockeye salmon to the Igushik River system, Bristol Bay, Alaska, in 1992 based on linear regression models using spawner-recruit and sibling data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	170	86	1.0	32
2.2	169	28	2.5	31
1.3	169	365	0.1	31
2.3	308	42	0.1	30
	Total	521		

Sibling Data

Age Class	Sibling Return in 1991 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[a]	NS	3
2.2	0	[a]	25.0	5
1.3	167	392	2.5	35
2.3	27	32	<0.1	35
	Total	424		

[a] Estimates not made; zero age-1.1 and zero age-2.1 siblings returned to Igushik River in 1991.

Appendix C.8. Forecasted returns of major age classes of sockeye salmon to the Togiak River system, Bristol Bay, Alaska, in 1992 based on linear regression models using spawner-recruit and sibling data.

Spawner-Recruit Data

Age Class	Spawning Escapement (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	309	88	1.0	32
2.2	250	26	1.0	31
1.3	250	335	0.5	31
2.3	203	26	<0.1	30
	Total	475		

Sibling Data

Age Class	Sibling Return in 1991 (thousands)	Predicted Return (thousands)	Approximate Significance Level (%)	Sample Size
1.2	0	[a]	NS	12
2.2	0	[a]	NS	6
1.3	199	305	0.5	34
2.3	87	38	0.5	34
	Total	343		

[a] Estimate not made; zero age-1.1 and age-2.1 siblings returned to Togiak River in 1990; regression models not significant at 25% level (P>0.25).